August 29, 2003

MEMORANDUM

SUBJECT: Analysis of Automated Surface Observation System (ASOS) Visibility Sensor Data to Evaluate Correlation with Nearby $PM_{2.5}$ Monitors

FROM: Jim Szykman, OAQPS
Rich Damberg, OAQPS

TO: PM NAAQS Review Docket (OAR-2001-0017)

The purpose of this memorandum is to describe and summarize analyses designed by EPA and conducted by EPA with support from RTI International (under contract no. 68-D-98-032) to determine correlations between the Automated Surface Observation System (ASOS) visibility sensor data from the National Weather Service (NWS) with $PM_{2.5}$ mass concentrations at nearby sites. These analyses were performed in order to evaluate the potential usefulness of the ASOS data in characterizing urban visibility and estimating $PM_{2.5}$ concentrations.

ASOS monitors are located at most major airports in the US. Their purpose is to measure meteorological parameters and visibility conditions to aid in air transportation safety and air traffic control. The monitors provide visibility measurements with 1-minute resolution. If readings from these monitors can be shown to be useful in estimating $PM_{2.5}$ mass concentrations, data from this existing network might enhance our understanding of $PM_{2.5}$ and associated urban visibility conditions across the United States.

Introduction

In 1974, the National Weather Service and Federal Aviation Administration (FAA) began an effort to develop an automated observation method to measure visibility at airports. As a result, deployment of two operational automated observing systems started in 1995: the Automated Weather Observation System (AWOS), primarily a system operating by the FAA and state governments; and the Automated Surface Observation System (ASOS), a joint NWS, FAA, and Department of Defense system. Between both networks over 1200 automated systems are in operation across the United States, with over 900 of these stations residing in the ASOS network.

The primary function of the ASOS is to provide minute-by-minute observations and generate the basic Aviation Routine Weather Report (METAR) and Aviation Selected Special Weather Report (SPECI) for safe and efficient aviation operations. For discerning visibility conditions, the ASOS network employs the Belfort Model 6200 visibility meter, a forward scattering light meter in which light from a pulsed Xenon flash lamp is transmitted twice a second in a cone-shaped beam over a range of angles in a 0.75 cu. ft. sample volume. (ASOS user guide) The range of extinction coefficients for the Belfort Model 6200 meter is 0.0186 to 0.062 km^{-1} (Belfort Model 6200 Operator's installation and maintenance manual). Previous research has suggested that light extinction readings are highly correlated with $PM_{2.5}$ concentrations, especially when the light extinction readings are adjusted for relative humidity (Richards et al., 1997).

Data and Methodology

In 2002, U.S. EPA's Office of Air and Radiation, Office of Air Quality Planning and Standards (OAQPS) issued a work assignment to RTI International to conduct a preliminary evaluation of ASOS visibility data to determine if the readings from these monitors can be useful in estimating $PM_{2.5}$ concentrations.

This evaluation involved the use of several data sets:

ASOS data - OAQPS obtained untruncated (high-resolution) one-minute 1999 ASOS data for 63 locations from the National Oceanic and Atmospheric Administration (NOAA), National Climactic Data Center (NCDC) archive.

Federal Reference Method (FRM) $PM_{2.5}$ mass data – Daily concentration of 1999 $PM_{2.5}$ mass data were extracted from the Aerometric Information Retrieval System (AIRS) measured in micrograms per cubic meter of ambient air ($\mu g/m^3$).

Interagency Monitoring of Protected Visual Environments (IMPROVE) data – 1999 quarterly concentrations from IMPROVE aerosol samplers for speciated fine mass aerosol concentrations and coarse mass aerosol concentrations derived from 24-hour mass concentrations.

Clean Air Status and Trends Network (CASTNet) data – 2000 quarterly speciated fine mass aerosol concentrations and coarse mass aerosol concentrations derived from 24-hour mass concentrations.

A brief description of the methodology used to estimate $PM_{2.5}$ concentrations from ASOS data is presented below. A more detailed discussion of the methodology and data screening criteria is provided in appendix A.

In general, the methodology involved the empirical determination of $PM_{2.5}$ concentrations using the IMPROVE reconstructed light extinction algorithm (Malm et. al. 1994). Because the ASOS visibility measurement uses a forward light scattering instrument, the IMPROVE algorithm (a function of both light scattering and light absorption) was modified to the following form to calculate light scattering only:

$$[PM_{2.5}]_{predicted} = \frac{b_{ext} - 10 - .6[CM]}{3f(RH)[X_{SO_4,NO_3}] + 4[X_{OC}] + [X_{SOIL}]}$$

where

$[PM_{2.5}]_{predicted}$ = predicted concentration of $PM_{2.5}$ in $\mu g/m^3$ at ASOS site
b_{ext} = light extinction coefficient in Mm^{-1} from ASOS data
$[X_{SO4}]$ = weight percent of ammonium sulfate component of $PM_{2.5}$
$[X_{NO3}]$ = weight percent of ammonium nitrate component of $PM_{2.5}$
$f(RH)$ = function of relative humidity
$[X_{OC}]$ = weight percent of organic carbon component of $PM_{2.5}$
$[X_{SOIL}]$ = weight percent of crustal material component of $PM_{2.5}$

[CM] = concentration of coarse mass (PM_{10} - $PM_{2.5}$) in $\mu g/m^3$

IMPROVE and CASTNet data from 1999 were used to calculate the weight percentages of the $PM_{2.5}$ components on a regional and seasonal basis. For example, IMPROVE data from Mammoth Cave and CASTNet data from LIV573 were used to calculate the weight percentages of $PM_{2.5}$ components and concentration of coarse mass (CM) used in the simplified IMPROVE algorithm at the Cincinnati ASOS site. These values are presented for each site in Appendix F.

Daily averages for light extinction, b_{ext} , were generated from the one-minute ASOS data. Screening criteria were used to eliminate certain data based on 1-minute, hourly and daily levels for completeness; extreme variations in ASOS readings; and high extinction coefficients attributable to precipitation.

The daily extinction values, PM2.5 component weight percents, and CM concentrations were used as inputs to the simplified IMPROVE algorithm to calculate a daily predicted concentration for $PM_{2.5}$, $[PM_{2.5}]_{predicted}$, for each ASOS site. A simple correlation was computed between $[PM_{2.5}]_{predicted,}$ (calculated from ASOS data) and $PM_{2.5}$ concentrations from Federal Reference Methods (FRM) monitoring sites located within 10 miles of the ASOS locations (see figure 1).

Results

Table 1 provides a summary of the correlation results, with site-specific results presented in appendix B. Although correlation results showed a fair amount of variability from site to site, correlations exceeded 0.70 in at least one quarter for 40 of the 49 cities. The annual average values across all sites were modestly correlated at 0.63. Correlations were more consistently high in the 3rd quarter (July-August-September), with correlations exceeding 0.70 at more than 50% of the sites.

Table 1 - Summary statistics of correlation results: $[PM_{2.5}]_{predicted}$ versus FRM $[PM_{2.5}]$

	Annual	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Maximum	0.90	0.99	1.00	0.94	0.99
Minimum	-0.05	-0.21	-0.85	-0.01	-0.22
Mean	0.63	0.51	0.62	0.76	0.63
Standard Deviation	0.20	0.34	0.36	0.21	0.30

Appendix C provides plots showing the relationship between seasonal correlations and the longitude coordinate of ASOS site. It appears that the correlation is better for sites in the Eastern US than the Western US for all four quarters.

Appendix D provides a scatter plot for each city, comparing the estimated PM2.5 values from ASOS data with PM2.5 values from the FRM monitor. A review of the scatter plots indicates the estimated PM2.5 values to be generally overestimated as compared to FRM monitor values.

Appendix E provides time series plots for each city, comparing the ASOS 24-hour averaged light extinction coefficient and $PM_{2.5}$ concentrations from FRM sites. The time series appear to have fairly good agreement, with increases and decreases in each metric occurring at the same time.

Conclusion and Recommendations

The results from this preliminary analysis exploring the use of ASOS visibility data to assess correlations with PM2.5 mass concentrations appear to be promising. Correlations tended to be higher for cities in the eastern U.S., and further work is recommended to determine why this is the case.

For this analysis, the percent mass of individual PM2.5 components at FRM sites was estimated using percentages derived from the closest speciated PM2.5 monitors in the primarily rural IMPROVE and CASTnet monitoring networks. Urban speciated monitoring data was not widely available at the time this analysis was performed. Future analyses using the now available speciated PM2.5 data from urban sites are recommended. It is expected that correlations would improve when using this more detailed dataset.

Some ASOS locations have multiple visibility sensors. Further analyses should be conducted to determine how well multiple sensors at the same airport are correlated.

For the purposes of reporting airport visibility, the raw data from ASOS sites is truncated to indicate visibility levels of 10 miles or less. In some cases, researchers have been able to obtain the raw data with special arrangements with FAA or NWS. In order for this high resolution 1-minute dataset to be more useful to a wide range of researchers and air quality professionals, the raw data from these sites should be made available more broadly, perhaps through a web-based archival system.

List of Appendices

Appendix A - Methodology and Data Screening Criteria
Appendix B - Correlations Between Calculated $PM_{2.5}$ Concentrations and FRM $PM_{2.5}$ Concentrations.
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Appendix D – Scatter plots $[PM_{2.5}]_{predicted}$ versus $PM_{2.5}$ concentrations from FRM sites
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Appendix F - Grouping of IMPROVE and CASTnet sites with ASOS sites, and values of $[CM]$, $[X_{SO4,NO3}]$, $[X_{OC}]$, and $[X_{SOIL}]$ for each matched group.

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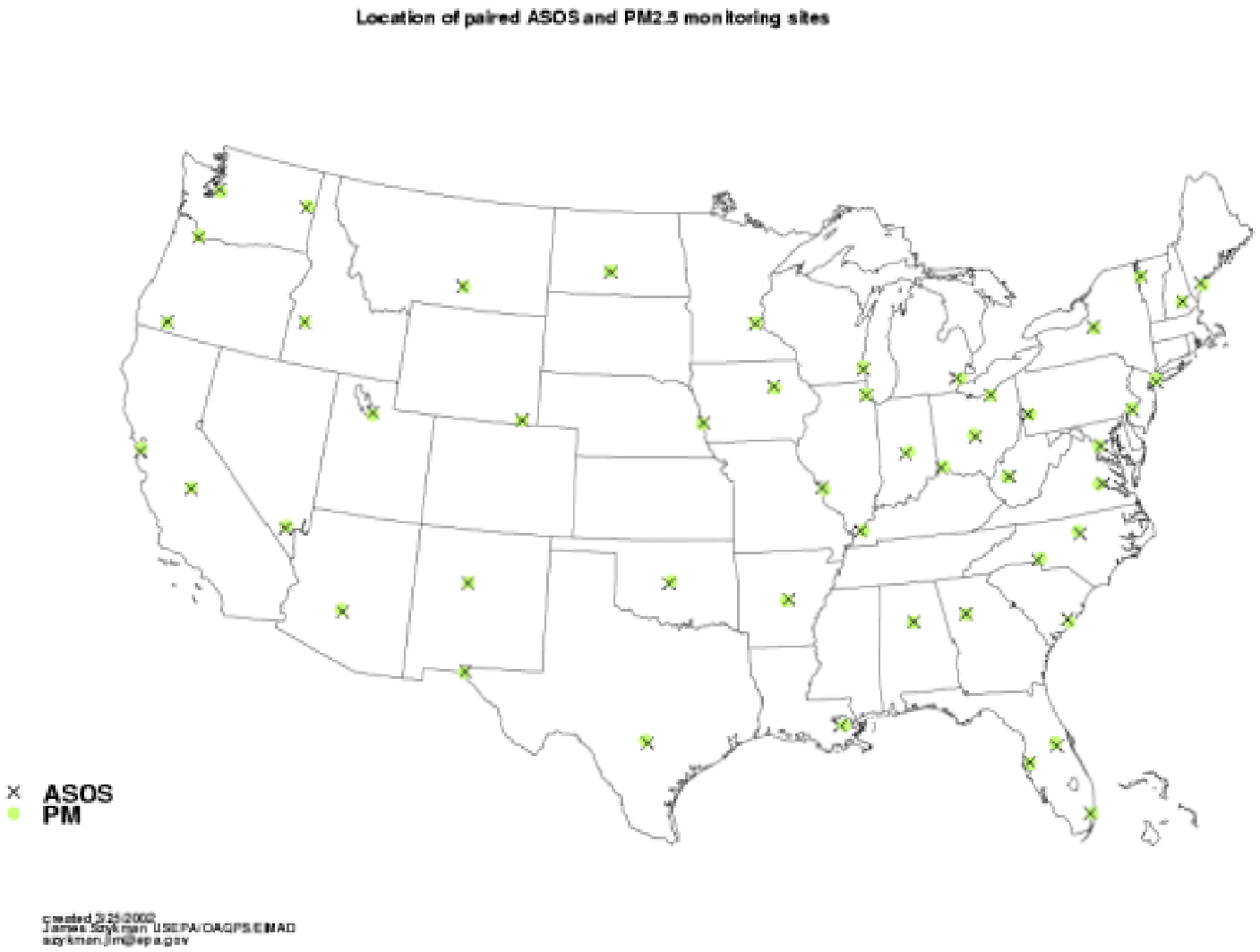
Location of paired ASOS and PM2.5 monitoring sites
ASOS
PM
created 2/25/2002
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Figure 1

Appendix A - Methodology and Data Screening Criteria.

Appendix A - Methodology and Data Screening Criteria

This appendix provides an outline of the data handling, processing and products associated with the study.

a) Computation of Daily Averages for the ASOS Sites.

EPA provided the following materials to RTI at the onset of the project:

i) One-minute ASOS data for 1999 on twelve CDs, for 63 sites. Each site has up to three extinction readings associated with it, because each site can have up to three monitors.
ii) A SAS program (DAILYRD.SAS) to use as a starting point for reading in the ASOS 1-minute data and for computing longer-term averages.
iii) A WordPerfect document (ASOSDATAPROCESS.WPD) describing flagging criteria.

RTI used DAILYRD.SAS to read in the one-minute data, compute hourly averages from the one-minute data, and implement certain flagging criteria. RTI extended the program to compute daily averages. The final flagging criteria used by RTI closely resemble the criteria provided in ASOSDATAPROCESS.WPD. The final flagging criteria are listed below.

At the 1-minute level:

i) If the relative humidity is greater than 98%, or both the precipitation code is not 'NP' (No Precipitation) and the relative humidity is greater than 90%, flag the 1-minute values for relative humidity and the three extinction readings.
ii) Calculate the arithmetic means of the unflagged 1-minute values for relative humidity and the three extinction readings, for each site/date/hour combination.
iii) Count the number of unflagged, nonmissing 1-minute values for relative humidity and the three extinction readings, for each site/date/hour combination.

At the hourly level:

i) Round off the arithmetic mean for relative humidity to the nearest integer, and link in the value of *f(RH)* from the spreadsheet. (See II(d) below).
ii) Link in the values of *[CM]*, $[X_{SO4,NO3}]$, $[X_{OC}]$, and $[X_{SOIL}]$ from a different spreadsheet. (See II(e) below.)
iii) If the mean relative humidity is greater than 95%, flag the three extinction means.
iv) For each of the three extinction means, if the mean from the current hour differs from the mean of the previous hour by more than 60 Mm-l, flag the current hour's mean.
v) For each of the three extinction means, flag if the reading is greater than 500 Mm-l.
vi) For each of the three extinction means and the relative humidity, flag if the number of unflagged, nonmissing observations for the hour is less than 45.
vii) For each of the three extinction means, flag if the mean is between two flagged means.
viii) Calculate the arithmetic means of unflagged, nonmissing hourly values for the relative humidity and the three extinction means, for each site/date combination.

At the daily level:

i) For each of the three extinction means, flag if the number of unflagged, nonmissing hourly values for the day is less than 18.
ii) If the number of unflagged, nonmissing relative humidity hourly values for the day is less than 18, flag all three extinction means.

For sites with more the one ASOS monitor, the first of the extinction readings listed in the NCDC archive data was used for all but two of the ASOS sites. For ABQ (Albuquerque, NM) and LAS (Las Vegas, NV), the first extinction reading was not used because there were extended periods of constant 1-minute readings from the monitor, indicating that the monitor was not functioning properly. The second extinction reading for ABQ and the third for LAS were used because the data were most complete for these monitors.

b) $PM_{2.5}$ Daily Concentrations.

Federal Reference Method (FRM) $PM_{2.5}$ mass data 1999 daily concentrations from the Aerometric Information Retrieval System (AIRS) were used as is. Monitors with the same AIRS site ID but different Pollutant Occurrence Codes (POCs) were treated as if they were one monitor.

c) Computation of $PM_{2.5}$ mass at ASOS sites using the IMPROVE Algorithm.

The IMPROVE algorithm for reconstructing light extinction from aerosol measurements is a function of light scattering and light absorption:

$$b_{ext} = b_{scat} + b_{abs} = b_{scat\_particle} + b_{scat\_gas} + b_{abs\_particle} + b_{abs\_gas}$$

where b_{scat} is the sum of scattering by gases, b_{scat_gas}, and scattering by particles, $b_{scat\_particle}$, and b_{abs} is the sum of absorption by gases, b_{abs_gas} and particles, $b_{abs\_particle}$. Scattering by gases, b_{scat_gas}, in the atmosphere is attributed to Rayleigh scattering. The IMPROVE program assumes a standard value of 10 inverse megameters. Scattering by particles is caused by both fine and coarse aerosol species and is the largest contributor to total light extinction in most locations [Malm et at., 1994, IMPROVE 2000 pg 3-1]. Absorption due to gases is primarily due to nitrogen dioxide and is assumed to be negligible in the IMPROVE program because most monitors are in rural locations [Trijonis and Pitchford, 1987]. Absorption by particles is caused primarily by black (or elemental) carbon. [Malm, 2000].

The IMPROVE algorithm used to estimate reconstructed light extinction is as follows:

$$b_{ext} = 3[SO_4]f(RH) + 3[NO_3]f(RH) + 4[OC] + 10[LAC] + [SOIL] + .6[CM] + 10$$

$$b_{ext} = \mathbf{(3)}\ f(RH)\ \mathbf{[}SO_4\mathbf{]} + \mathbf{(3)}\ f(RH)\mathbf{[}NO_3\mathbf{]} + \mathbf{(4)[}OC\mathbf{]} + \mathbf{[}SOIL\mathbf{]} + \mathbf{(10)\ [}LAC\mathbf{]} + \mathbf{(.6)\ [}CM\mathbf{]} + \mathbf{10}$$

where
b_{ext} = light extinction coefficient in Mm^{-1}
$[SO_4]$ = concentration of ammonium sulfate component of $PM_{2.5}$ in µg/m3
$[NO_3]$ = concentration of ammonium nitrate component of $PM_{2.5}$ in µg/m3
$f(RH)$ = function of relative humidity (described in (d) below)
$[OC]$ = concentration of organic carbon component of $PM_{2.5}$ in µg/m3
$[LAC]$ = concentration of light-absorbing carbon component of $PM_{2.5}$ in µg/m3
$[SOIL]$ = concentration of crustal material component of $PM_{2.5}$ in µg/m3
$[CM]$ = concentration of coarse mass (PM_{10} - $PM_{2.5}$) in µg/m3

Because the ASOS visibility measurement uses a forward light scattering instrument, the IMPROVE algorithm was simplified to the portion of the algorithm attributable to light scattering by eliminating the component representing light absorption due to elemental carbon. The IMPROVE algorithm was rearranged to express $PM_{2.5}$ as a function of b_{ext}.

$$[PM_{2.5}]_{predicted} = \frac{b_{ext} - 10 - .6[CM]}{3f(RH)[X_{SO_4,NO_3}] + 4[X_{OC}] + [X_{SOIL}]}$$

where

$[PM_{2.5}]_{predicted}$ = predicted concentration of $PM_{2.5}$ in µg/m3 at ASOS site
b_{ext} = light extinction coefficient in Mm^{-1} from ASOS data
$[X_{SO4}]$ = weight percent of ammonium sulfate component of $PM_{2.5}$
$[X_{NO3}]$ = weight percent of ammonium nitrate component of $PM_{2.5}$
$f(RH)$ = function of relative humidity (described in (d) below)
$[X_{OC}]$ = weight percent of organic carbon component of $PM_{2.5}$
$[X_{SOIL}]$ = weight percent of crustal material component of $PM_{2.5}$
$[CM]$ = concentration of coarse mass (PM_{10} - $PM_{2.5}$) in µg/m3
10 = standard value for Rayleigh scattering assumed by IMPROVE: 1/Mm

d) Relative Humidity Adjustment Factor f(RH).

EPA provided RTI with a file containing f(RH) factors for relative humidity values from 0 to 98 percent. These factors are the same as those used in the IMPROVE program and in EPA guidance.

e) $PM_{2.5}$ Species Composition and Coarse Mass.

EPA evaluated 1999 quarterly averages of data from IMPROVE and CASTnet sites to develop a table of estimated percentages for PM2.5 components that could be used in calculations for each ASOS site. Appendix F provides the grouping of IMPROVE and CASTnet sites along with the matched ASOS sites, and includes values of $[CM]$, $[X_{SO4,NO3}]$, $[X_{OC}]$, and $[X_{SOIL}]$ for each matched group.

f) Pairing of ASOS Sites with $PM_{2.5}$ Sites.

EPA provided RTI with two SAS data sets containing site location data: one with geographic (latitude/longitude) coordinates for the ASOS sites, and one with geographic coordinates for the $PM_{2.5}$ sites. EPA also provided RTI with a program for measuring the distance between two latitude/longitude coordinates. Using these inputs, RTI identified all of the $PM_{2.5}$ sites within 10 miles of each ASOS site for use in the analysis.

g) Data Table for Each Site Pair.

For each site pair, RTI calculated seasonal and annual PM2.5 concentrations for ASOS locations using the algorithm described above. RTI also calculated correlations between estimated PM2.5 values for ASOS sites and PM2.5 FRM sites. Seasonal groupings were based on calendar quarters. The number of observations used to calculate the seasonal and annual correlations is presented, and the distance between sites is presented as well. A summary of these correlations is provided in appendix B.

h) Scatter Plots for Each Site Pair

For each site pair, RTI prepared scatter plots comparing the predicted $PM_{2.5}$ concentrations on the vertical axis and the measured $PM_{2.5}$ concentrations on the horizontal axis. The data were paired for each day with valid readings. Each plot also shows the 45° line to evaluate whether the modeled concentrations overestimate or underestimate the measured concentrations. The correlation coefficient, number of data points, and intersite distance are displayed in the lower left corner of the plots. Site pairs with fewer than ten points in the scatter plot were discarded.

i) Time Series Plots for Each Site Pair.

For each site pair, RTI prepared time series plots by plotting both $PM_{2.5}$ and light extinction against time, overlaid on the same axes. These figures illustrate the degree to which the values of the two time series track one another.

Appendix B- Correlations Between Calculated $PM_{2.5}$ Concentrations and FRM $PM_{2.5}$ Concentrations

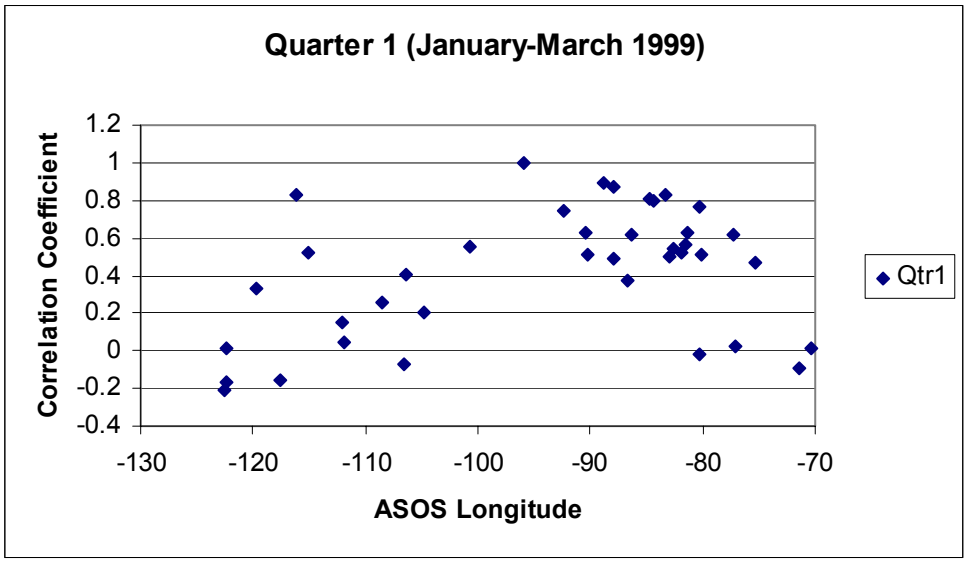
Table B-1
Correlations Between Calculated PM2.5 Concentrations and Federal Reference Method PM2.5 Concentrations
(Calculated PM2.5 concentrations using IMPROVE algorithm, and IMPROVE and CASTNET data)

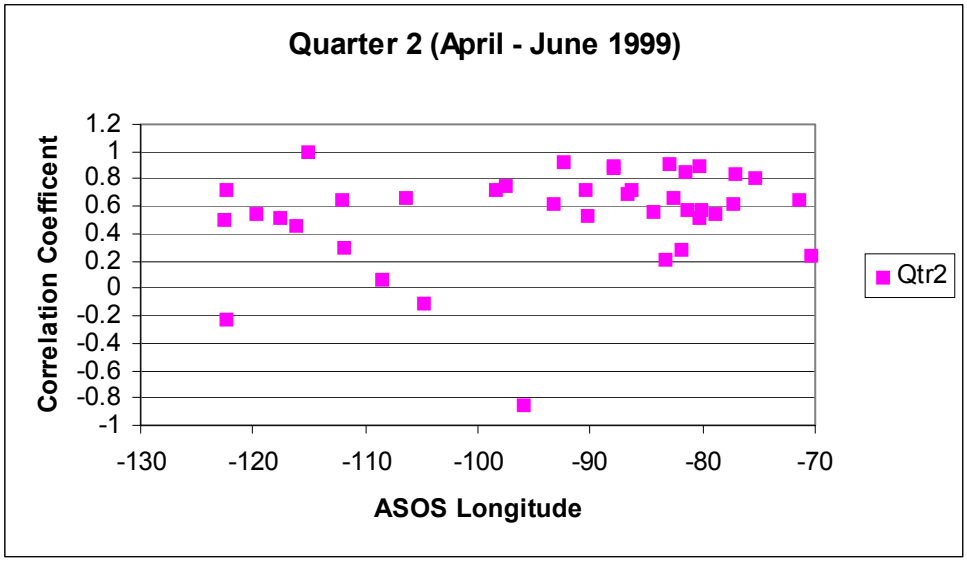
ASOS ID	Fed Ref Meth. PM2.5 Site ID	City	State	Dist. between ASOS & PM2.5 Sites (mi.)	Annual Corr.	Annual No. of obs.	Quarter 1 (Jan-Feb-Mar) Correlation	Quarter 1 No. of obs.	Quarter 2 (Apr-May-Jun) Correlation	Quarter 2 No. of obs.	Quarter 3 (Jul-Aug-Sep) Correlation	Quarter 3 No. of obs.	Quarter 4 (Oct-Nov-Dec) Correlation	Quarter 4 No. of obs.
BHM	10730023	Birmingham	AL	3.6	0.50	187	0.38	52	0.69	47	0.57	54	0.38	34
LIT	51191008	Little Rock	AR	6.7	0.70	42					0.76	23	0.63	19
PHX	40139997	Phoenix	AZ	6.8	0.73	272	0.15	63	0.64	73	0.46	78	0.81	58
FAT	60195001	Fresno	CA	3.0	0.88	44	0.34	12	0.54	13	0.89	12	0.91	7
SFO	60750005	San Francisco	CA	9.4	0.80	41	-0.16	6	-0.24	6	0.83	10	0.88	19
DCA	510591004	Washington	DC	5.8	0.71	50	0.03	12	0.83	20	0.93	15	0.98	3
MIA	120251016	Miami	FL	5.2	0.52	206	0.76	37	0.52	63	0.84	61	0.05	45
MCO	120951004	Orlando	FL	8.6	0.65	172	0.62	39	0.57	50	0.78	44	0.63	39
TPA	120570030	Tampa	FL	3.3	0.62	199	0.55	49	0.66	65	0.85	54	0.72	31
ATL	131211001	Atlanta	GA	1.8	0.75	54	0.80	12	0.55	16	0.88	14	0.56	12
ALO	190130008	Waterloo	IA	5.3	0.60	48	0.74	9	0.92	10	0.70	14	0.61	15
BOI	160010017	Boise	ID	2.4	0.72	61	0.83	9	0.45	13	0.73	22	0.59	17
ORD	170314006	Chicago	IL	3.3	0.58	28	0.49	5	0.90	8	0.51	10	0.90	5
IND	180970083	Indianapolis	IN	10.0	0.68	164	0.62	42	0.72	52	0.56	34	0.81	36
PAH	211451004	Paducah	KY	7.5	0.90	12	0.90	12						
MSY	220710012	New Orleans	LA	9.3	0.61	60	0.51	13	0.53	19	0.72	18	0.77	10
PWM	230052003	Portland	ME	7.8	0.47	47	0.02	6	0.24	19	0.47	17	0.10	5
DTW	261630036	Detroit	MI	9.7	0.63	39	0.83	6	0.20	12	0.92	12	0.94	9
MSP	271230872	Minneapolis	MN	4.6	0.64	27			0.62	10	0.79	9	0.75	8
STL	295100086	St. Louis	MO	8.4	0.74	198	0.62	42	0.72	62	0.87	68	0.49	26
BIL	301111065	Billings	MT	5.7	0.38	75	0.26	16	0.07	18	0.71	25	0.54	16
CLT	371190041	Charlotte	NC	9.2	0.78	61					0.85	29	0.63	32
RDU	370630001	Raleigh	NC	10.0	0.52	114			0.54	64	0.55	27	0.45	23
BIS	380150003	Bismarck	ND	3.7	0.42	12	0.55	6					0.41	6
OMA	310550019	Omaha	NE	5.7	0.46	40	1.00	3	-0.85	5	0.45	16	0.68	16
CON	330130003	Concord	NH	1.8	0.34	48	-0.10	12	0.65	19	-0.01	11	0.41	6
ABQ	350010024	Albuquerque	NM	2.3	-0.05	196	-0.07	34		11	0.32	72	-0.22	79
LAS	320032002	Las Vegas	NV	7.8	0.54	49	0.52	17	1.00	2	0.52	20	0.34	10
JFK	360810097	New York	NY	8.1	0.83	25					0.84	14	0.81	11
SYR	360671015	Syracuse	NY	4.7	0.80	21					0.84	17	0.94	4
CVG	211170007	Cincinnati	OH	7.6	0.81	11	0.81	11						
CLE	390351002	Cleveland	OH	1.9	0.46	66	0.52	15	0.28	17	0.87	17	-0.22	17
CMH	390490081	Columbus	OH	7.2	0.75	44	0.50	10	0.91	6	0.81	14	0.77	14
OKC	401090038	Oklahoma City	OK	9.3	0.66	50			0.75	11	0.65	19	0.46	20
MFR	410292129	Medford	OR	2.8	0.88	46					0.94	13	0.88	33
PDX	530110013	Portland	OR	4.2	0.18	53	-0.21	12	0.49	21	0.19	11	0.34	9
PHL	421010136	Philadelphia	PA	4.1	0.63	61	0.47	20	0.80	24	0.76	17		
PIT	420030116	Pittsburgh	PA	8.3	0.65	38	-0.02	9	0.90	8	0.83	9	0.47	12
CHS	450190049	Charleston	SC	8.8	0.51	139	0.52	48	0.57	43	0.76	24	0.11	24
ELP	481410044	El Paso	TX	5.4	0.24	127	0.41	28	0.66	39	0.76	15	0.20	45

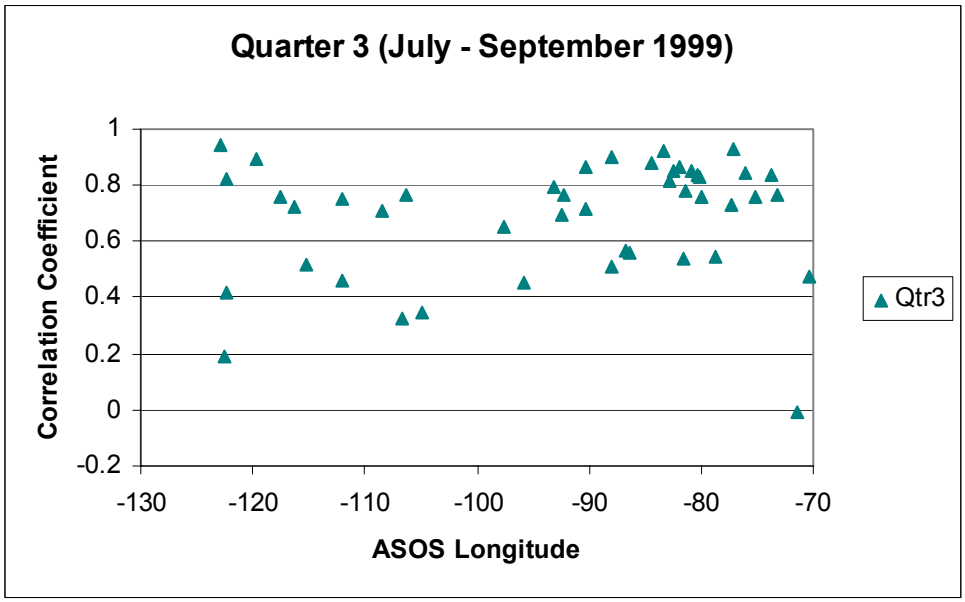
ASOS ID	Fed Ref Meth. PM2.5 Site ID	City	State	Dist. between ASOS & PM2.5 Sites (mi.)	Annual Corr.	Annual No. of obs.	Quarter 1 (Jan-Feb-Mar) Correlation	Quarter 1 No. of obs.	Quarter 2 (Apr-May-Jun) Correlation	Quarter 2 No. of obs.	Quarter 3 (Jul-Aug-Sep) Correlation	Quarter 3 No. of obs.	Quarter 4 (Oct-Nov-Dec) Correlation	Quarter 4 No. of obs.
SAT	480290052	San Antonio	TX	8.9	0.73	24			0.72	12			0.76	11
SLC	490353007	Salt Lake City	UT	5.9	0.64	66	0.05	11	0.30	26	0.75	21	0.73	8
RIC	517600020	Richmond	VA	9.8	0.53	143	0.62	39	0.61	51	0.73	43	0.40	10
BTV	500070012	Burlington	VT	3.2	0.62	25					0.77	13	0.77	12
SEA	530332004	Seattle	WA	5.7	0.42	61	0.02	12	0.72	22	0.42	20	0.27	7
GEG	530630047	Spokane	WA	7.6	0.81	50	-0.16	9	0.51	26	0.76	10	0.99	5
MKE	550790099	Milwaukee	WI	6.7	0.78	69	0.87	12	0.89	19	0.90	23	0.69	15
CRW	540391005	Charleston	WV	5.5	0.59	42	0.56	15	0.86	14	0.54	5	0.77	8
CYS	560210001	Cheyenne	WY	1.1	0.19	82	0.20	19	-0.12	22	0.35	21	0.41	20

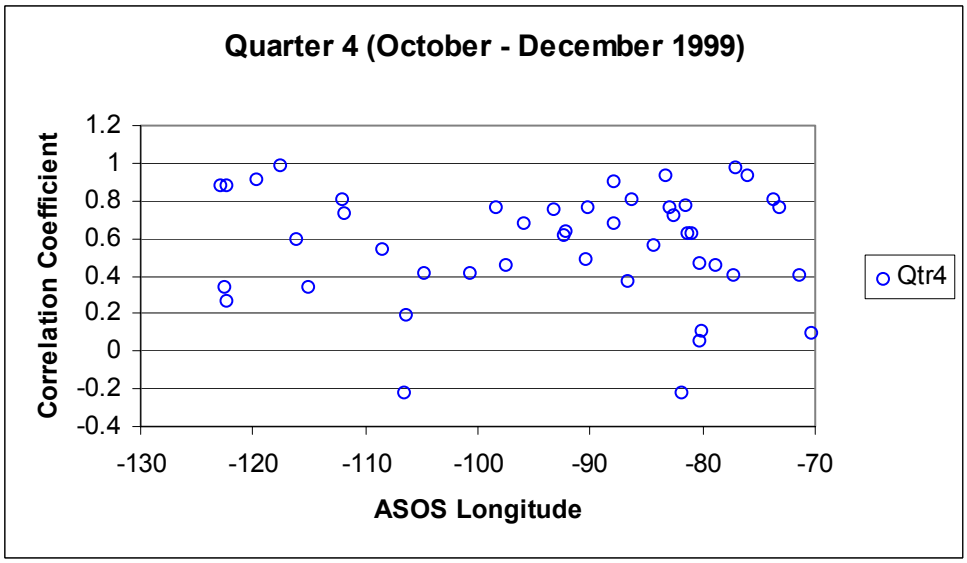
Appendix C

Relationship Between Correlations and Longitude Coordinate of ASOS Site.


Quarter 1 (January-March 1999)
Correlation Coefficient
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-130
-120
-110
-100
-90
-80
-70
ASOS Longitude
Qtr1


Quarter 2 (April - June 1999)
Correlation Coefficent
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-130
-120
-110
-100
-90
-80
-70
ASOS Longitude
Qtr2

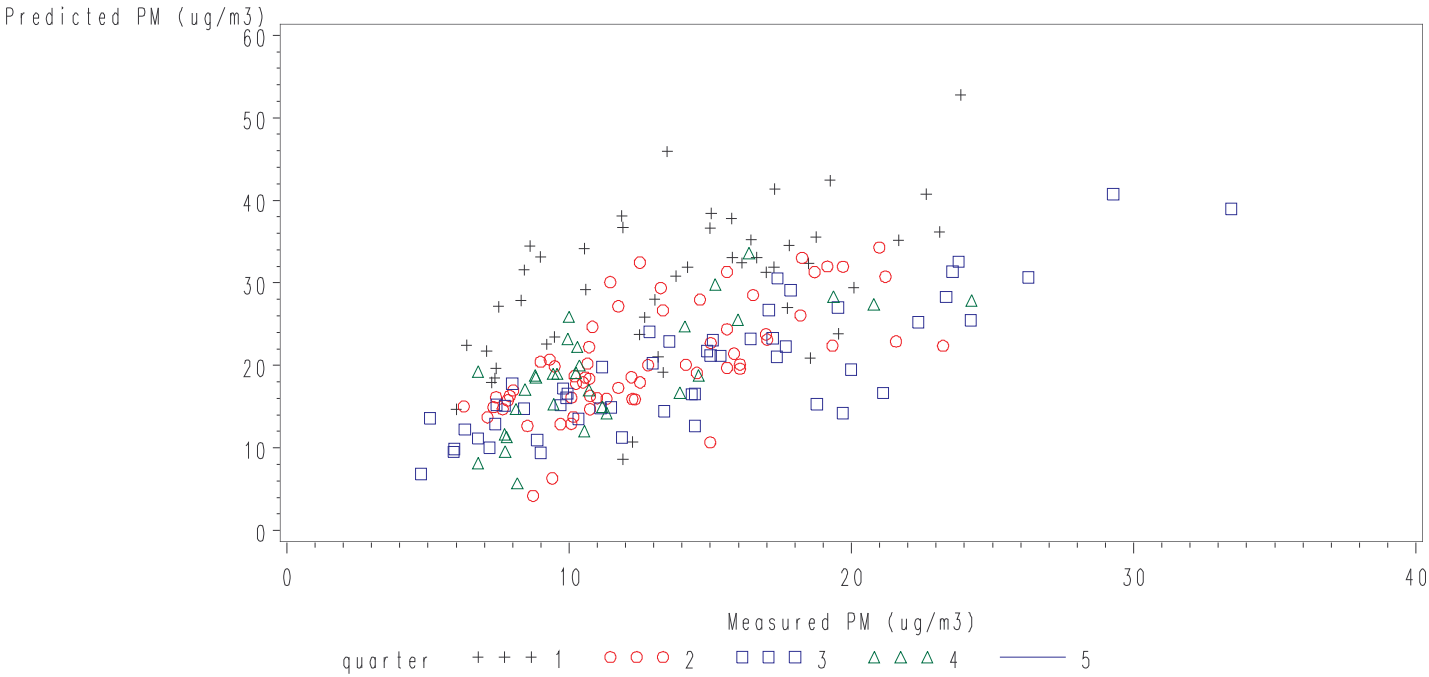

Quarter 3 (July - September 1999)
Correlation Coefficient
1
0.8
0.6
0.4
0.2
0
-0.2
-130
-120
-110
-100
-90
-80
-70
ASOS Longitude
Qtr3


Quarter 4 (October - December 1999)
Correlation Coefficient
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-130
-120
-110
-100
-90
-80
-70
ASOS Longitude
Qtr4

Appendix D – Scatter plots $[PM_{2.5}]_{predicted}$ versus $PM_{2.5}$ concentrations from FRM sites

Site Pair: ASOS=TPA , PM=120570030

Predicted vs Measured PM Fine
IMPROVE Model

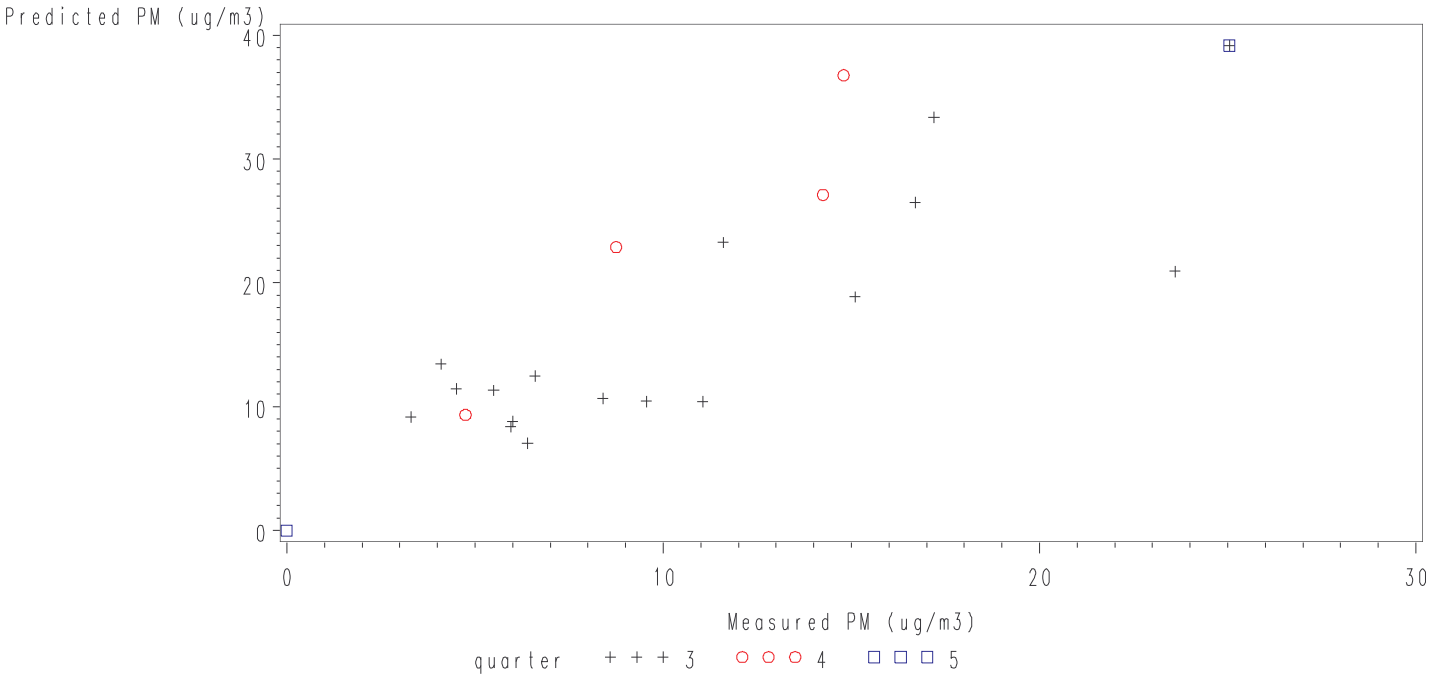


R = 0.6171
N = 199
Distance = 3.3 mi.

19MAR02:17:13:26

Site Pair: ASOS=SYR , PM=360671015

Predicted vs Measured PM Fine
IMPROVE Model

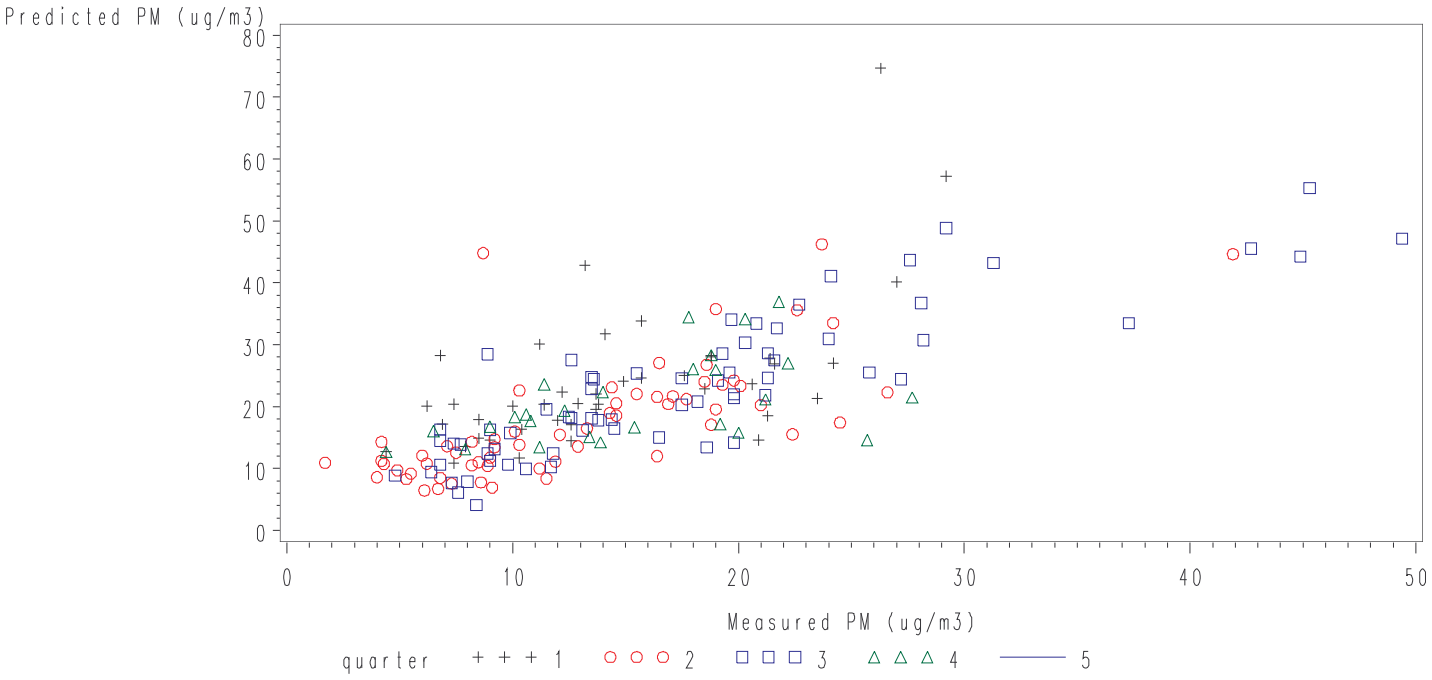


R = 0.7973
N = 21
Distance = 4.7 mi.

19MAR02:17:13:26

Site Pair: ASOS = STL , PM = 295100086

Predicted vs Measured PM Fine
IMPROVE Model

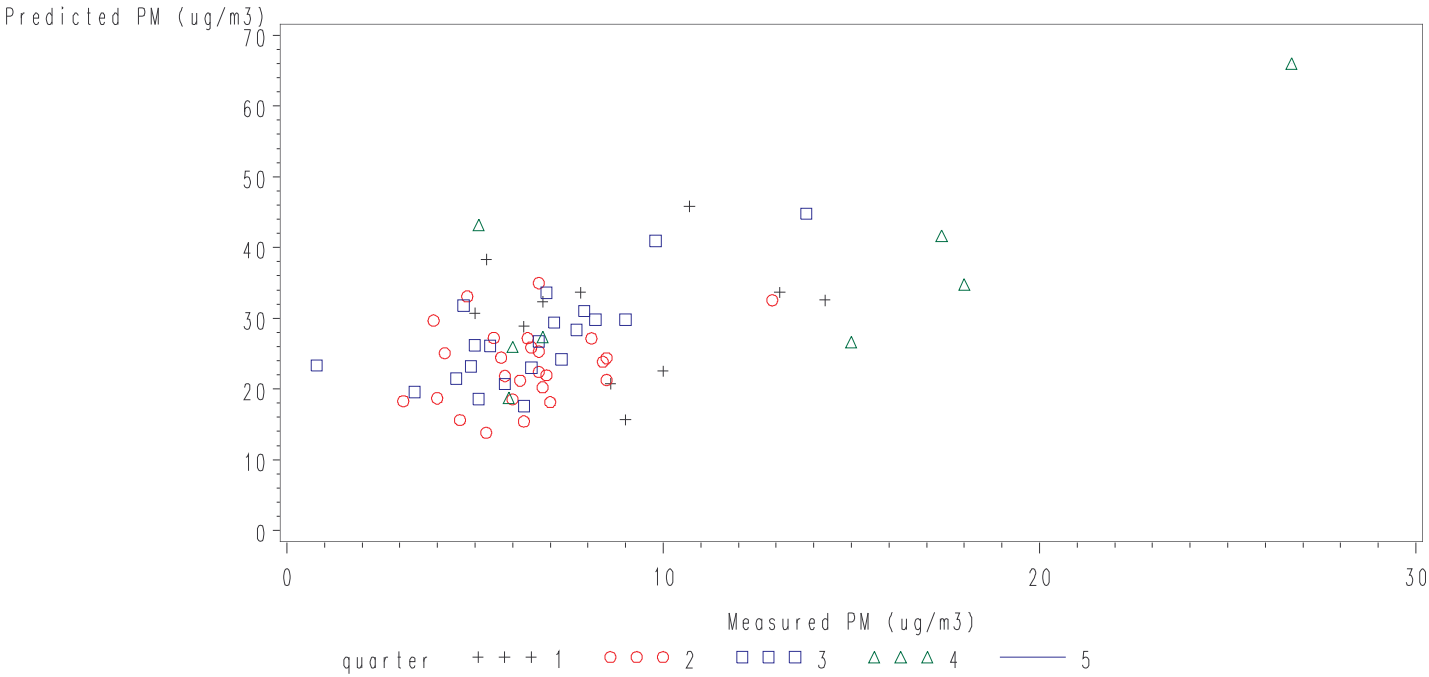


R = 0.7419
N = 198
Distance = 8.4 mi.

19MAR02:17:13:26

Site Pair: ASOS = SLC , PM = 490353007

Predicted vs Measured PM Fine
IMPROVE Model

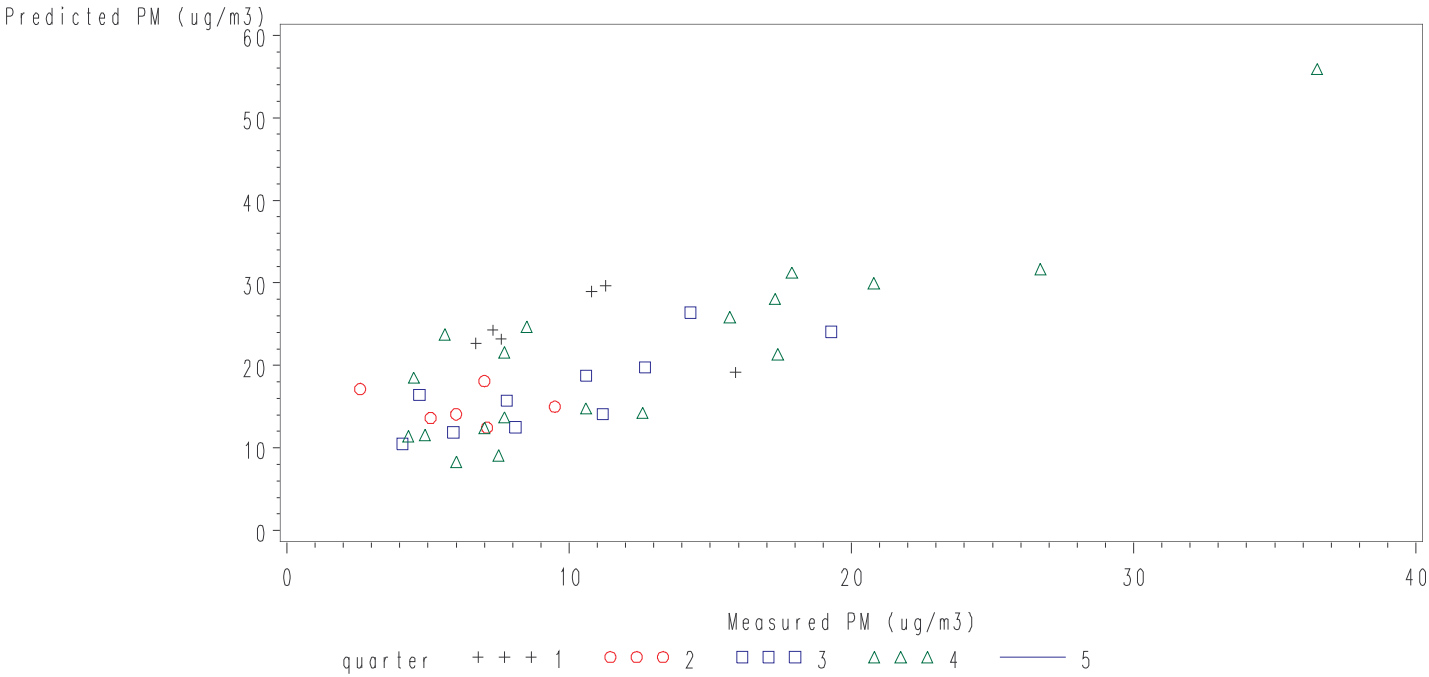


R = 0.6417
N = 66
Distance = 5.9 mi.

19MAR02:17:13:26

Site Pair: ASOS = SFO , PM = 060750005

Predicted vs Measured PM Fine
IMPROVE Model

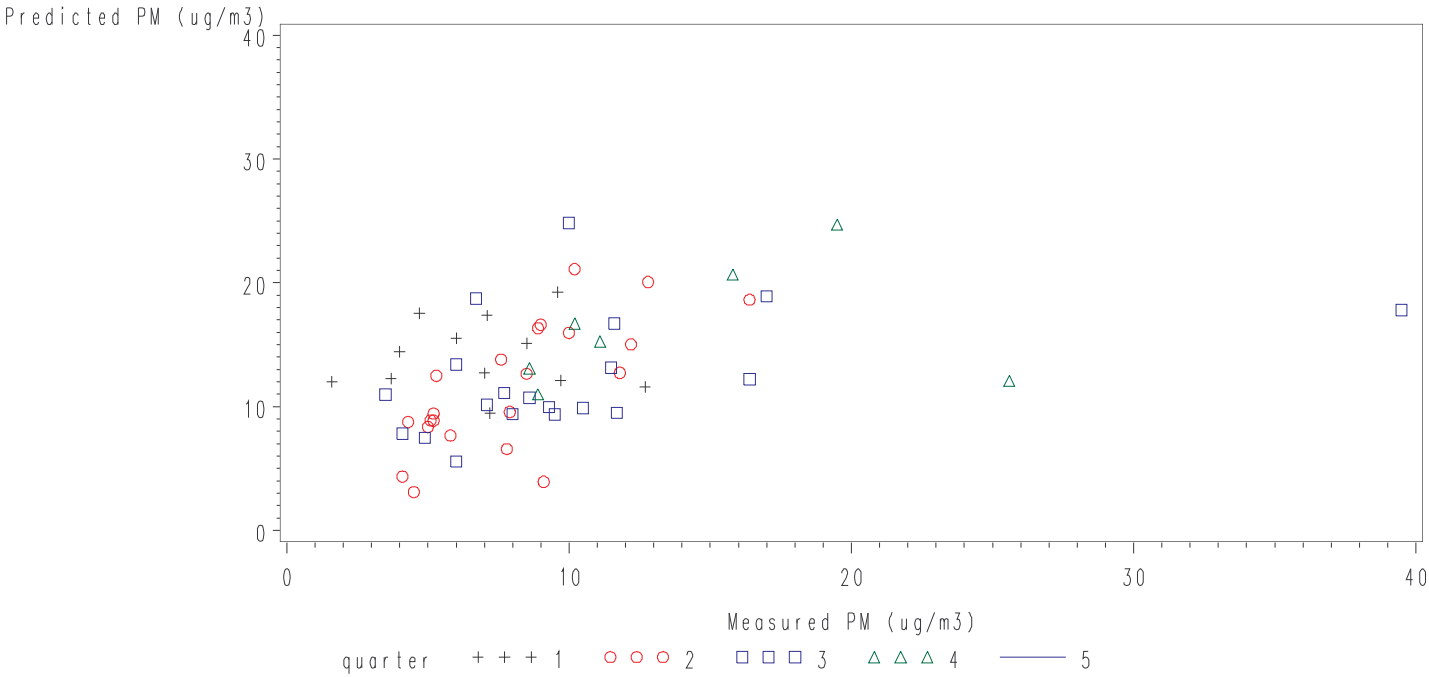


R = 0.8023
N = 41
Distance = 9.4 mi.

19MAR02:17:13:26

Site Pair: ASOS = SEA , PM = 530332004

Predicted vs Measured PM Fine
IMPROVE Model

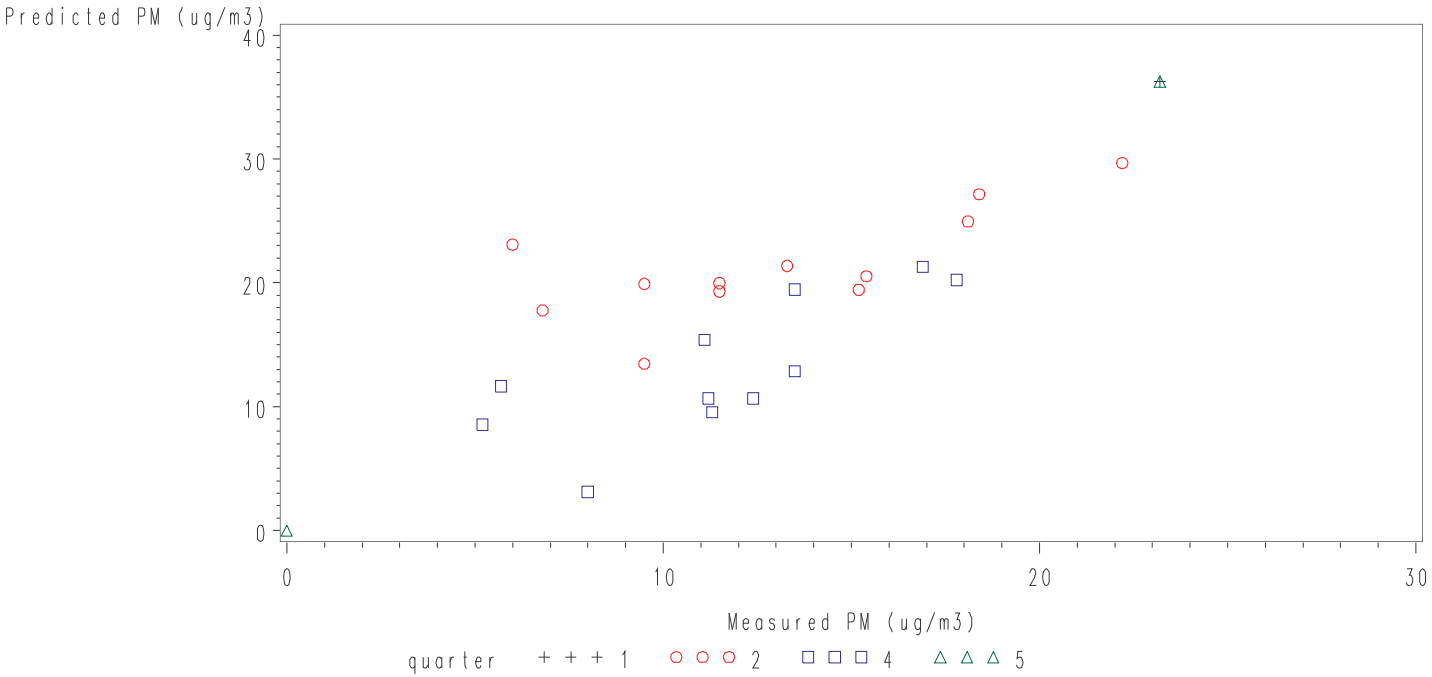


R = 0.4228
N = 61
Distance = 5.7 mi.

19MAR02:17:13:26

Site Pair: ASOS = SAT , PM = 480290052

Predicted vs Measured PM Fine
IMPROVE Model

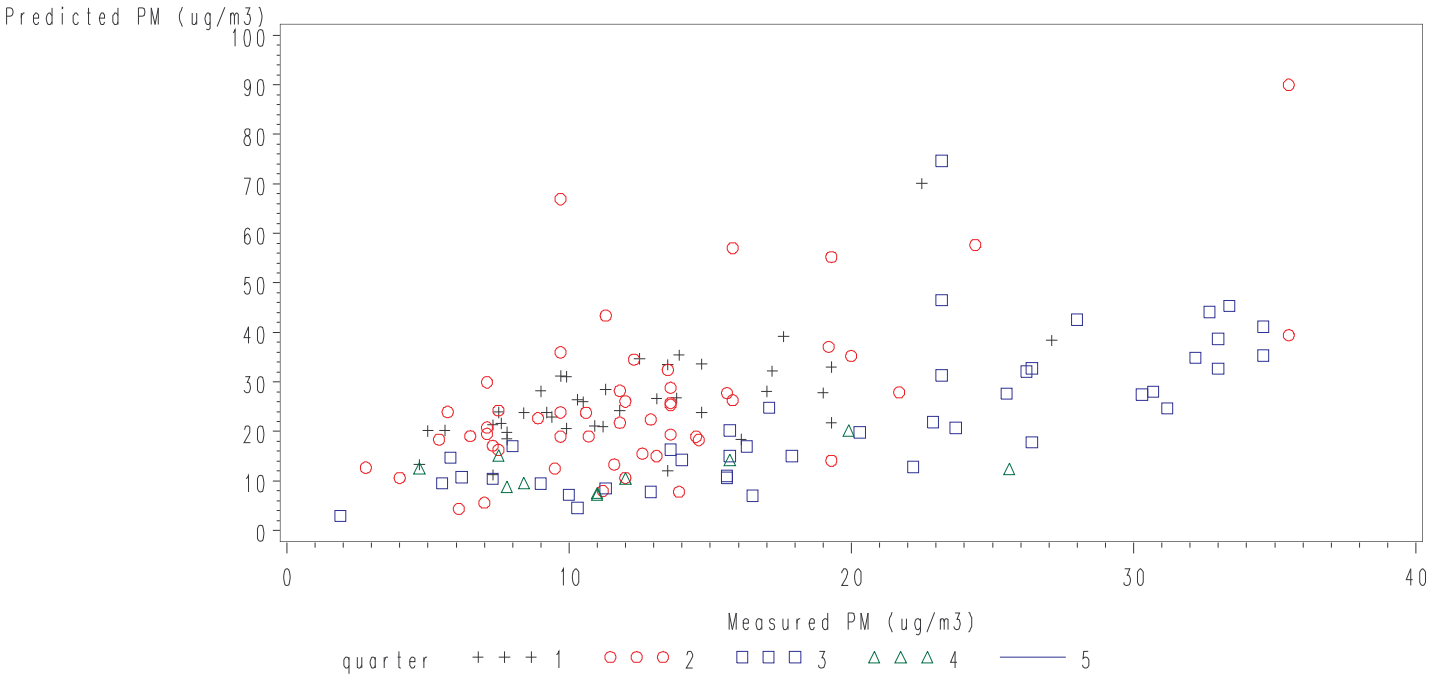


R = 0.7314
N = 24
Distance = 8.9 mi.

19MAR02:17:13:26

Site Pair: ASOS = RIC , PM = 517600020

Predicted vs Measured PM Fine
IMPROVE Model

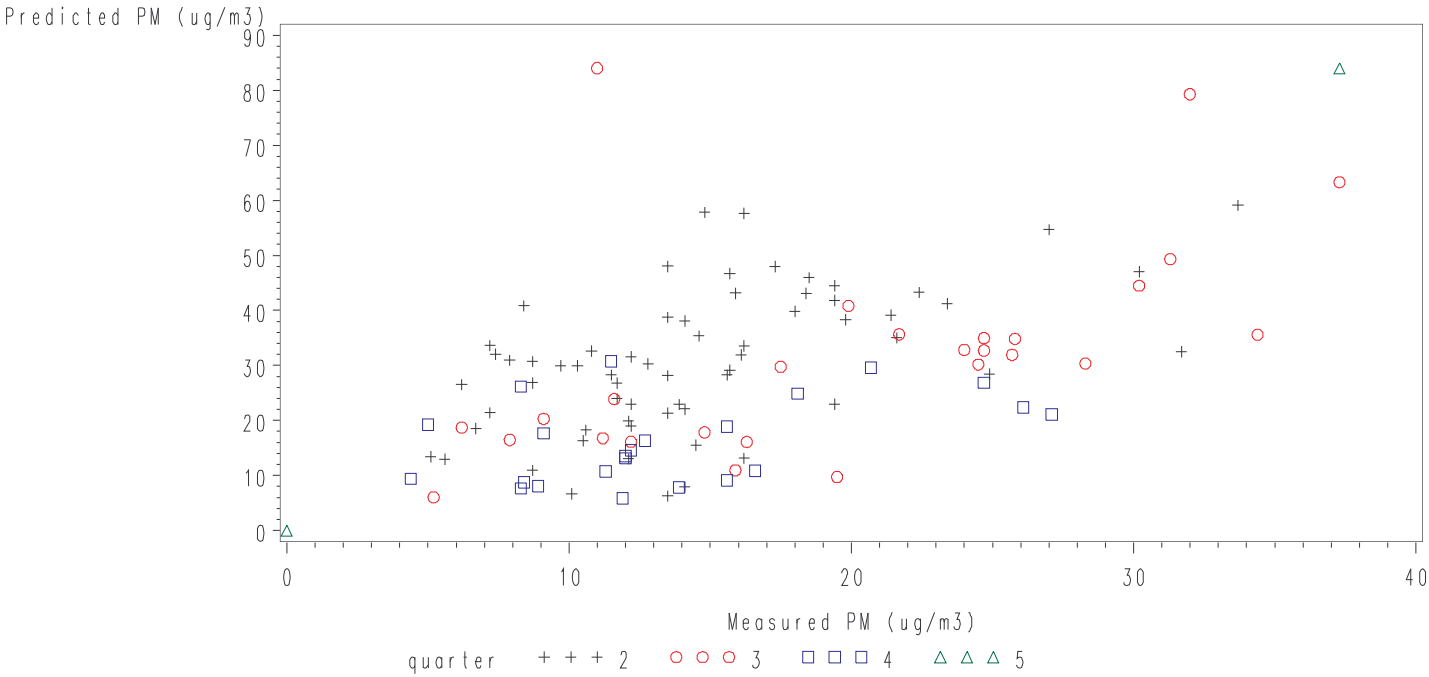


R = 0.5256
N = 143
Distance = 9.8 mi.

19MAR02:17:13:26

Site Pair: ASOS = RDU , PM = 370630001

Predicted vs Measured PM Fine
IMPROVE Model

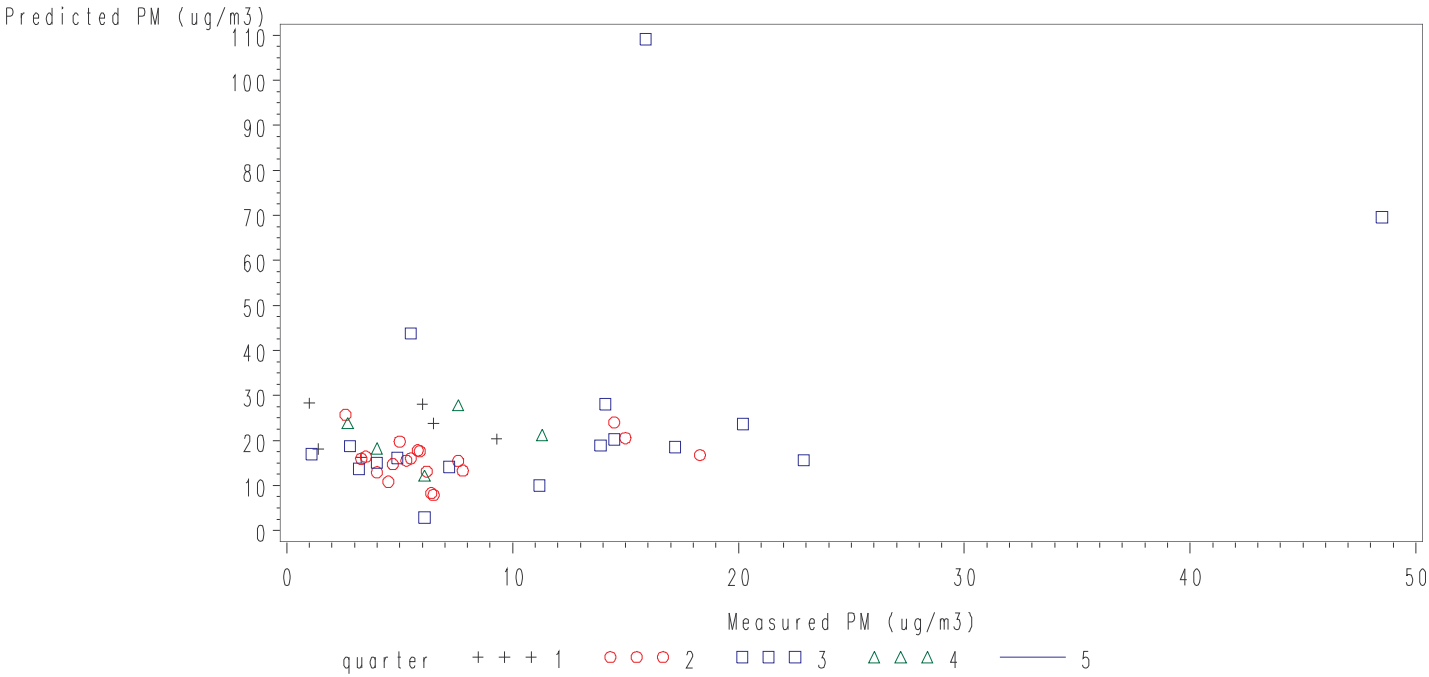


R = 0.5224
N = 114
Distance = 10 mi.

19MAR02:17:13:26

Site Pair: ASOS = PWM , PM = 230052003

Predicted vs Measured PM Fine
IMPROVE Model

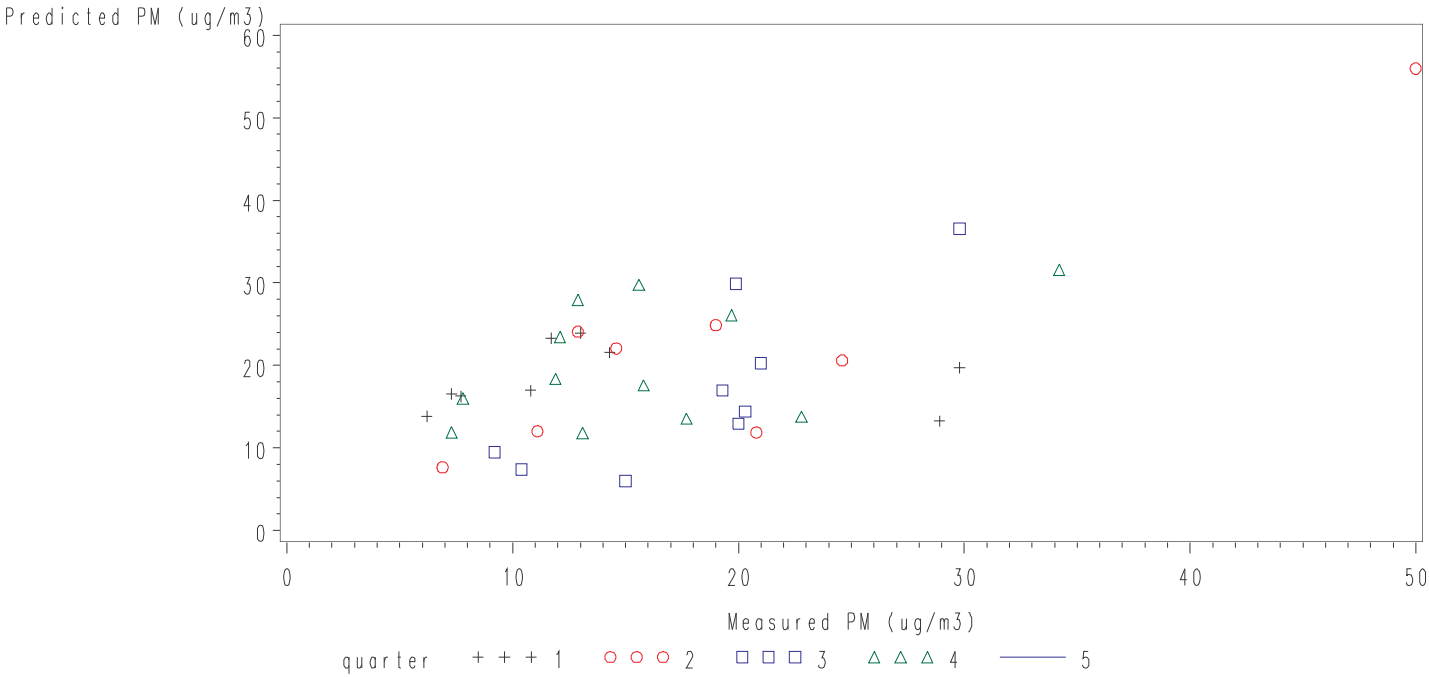


R = 0.4693
N = 47
Distance = 7.8 mi.

19MAR02:17:13:26

Site Pair: ASOS = PIT , PM = 420030116

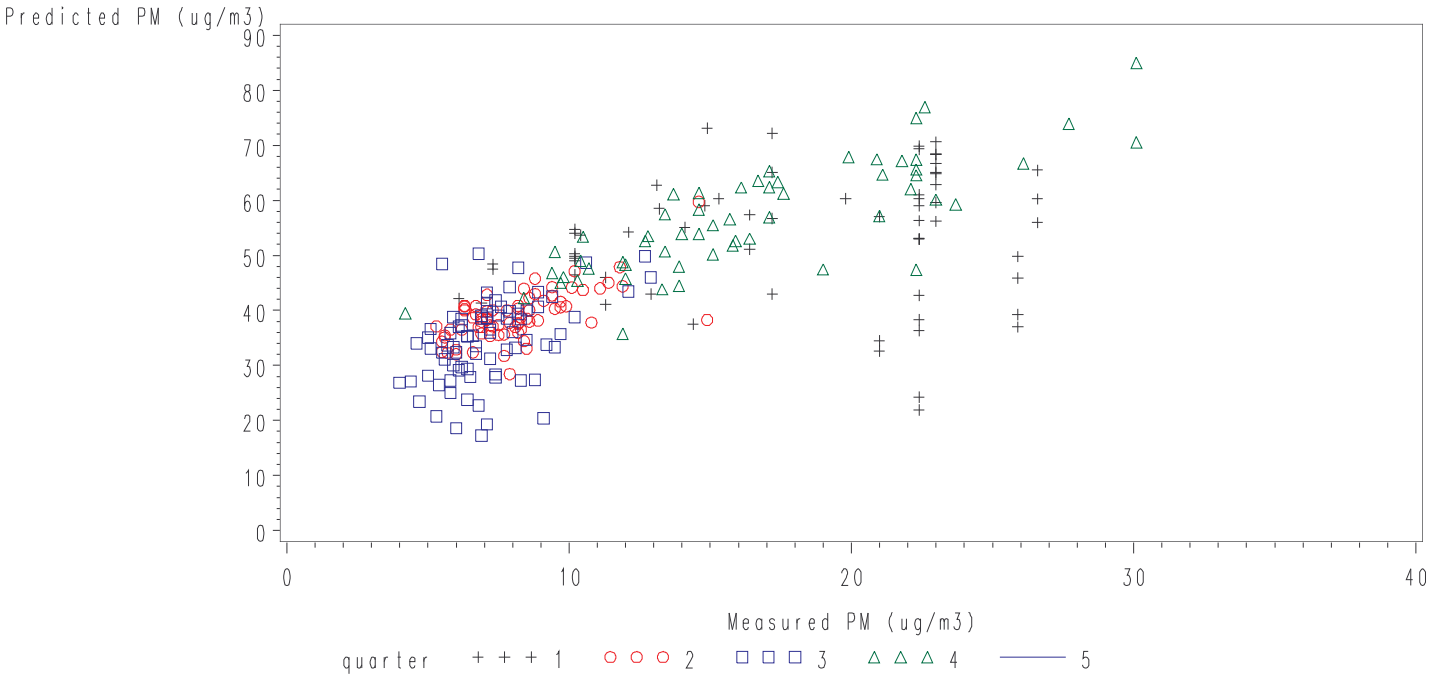
Predicted vs Measured PM Fine
IMPROVE Model



R = 0.6494
N = 38
Distance = 8.3 mi.

Site Pair: ASOS = PHX , PM = 040139997

Predicted vs Measured PM Fine
IMPROVE Model

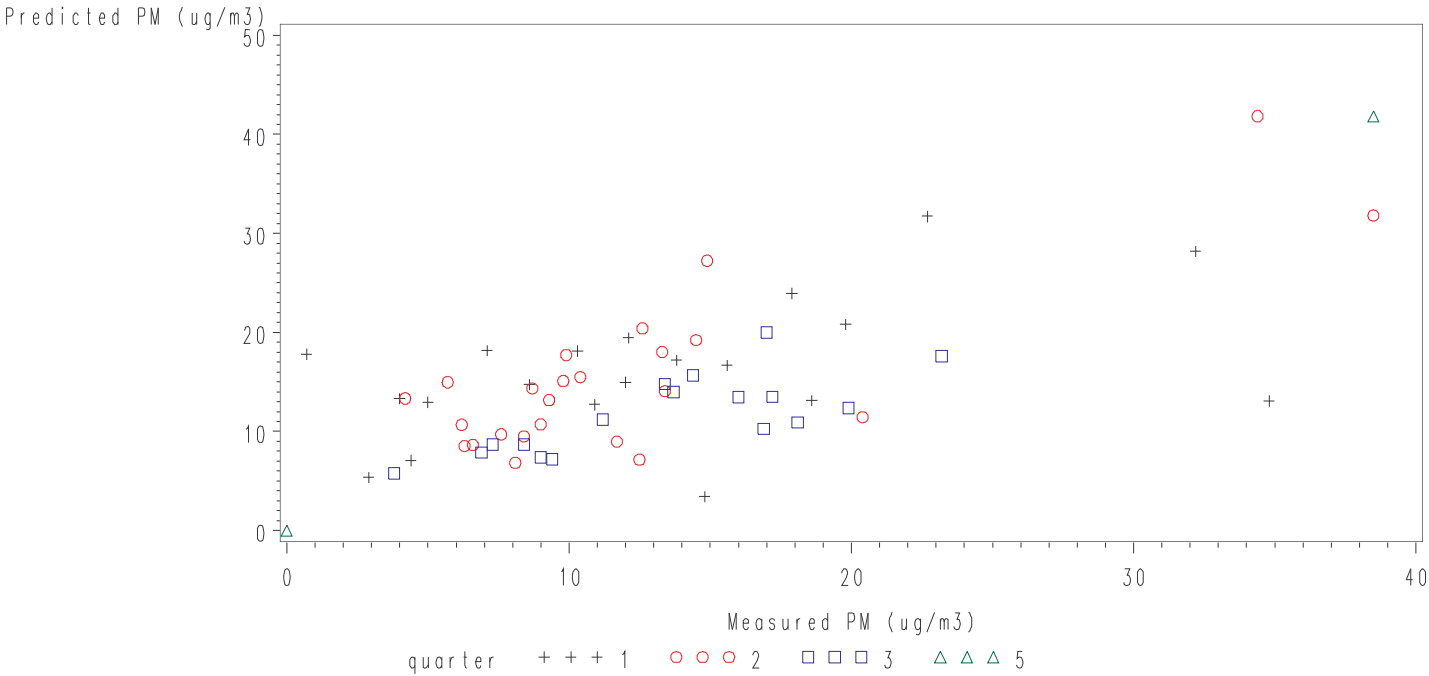


R = 0.7329
N = 272
Distance = 6.8 mi.

19MAR02:17:13:26

Site Pair: ASOS = PHL , PM = 421010136

Predicted vs Measured PM Fine
IMPROVE Model

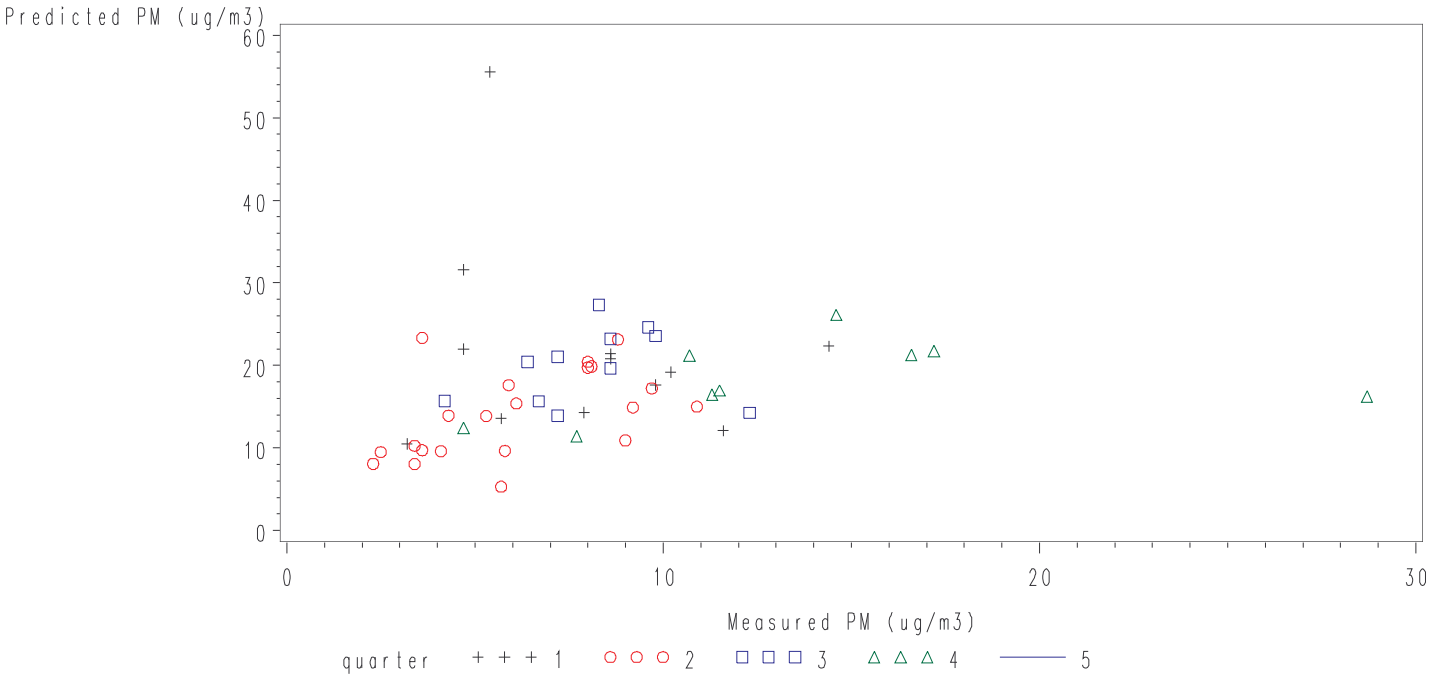


R = 0.6326
N = 61
Distance = 4.1 mi.

19MAR02:17:13:26

Site Pair: ASOS = PDX , PM = 530110013

Predicted vs Measured PM Fine
IMPROVE Model

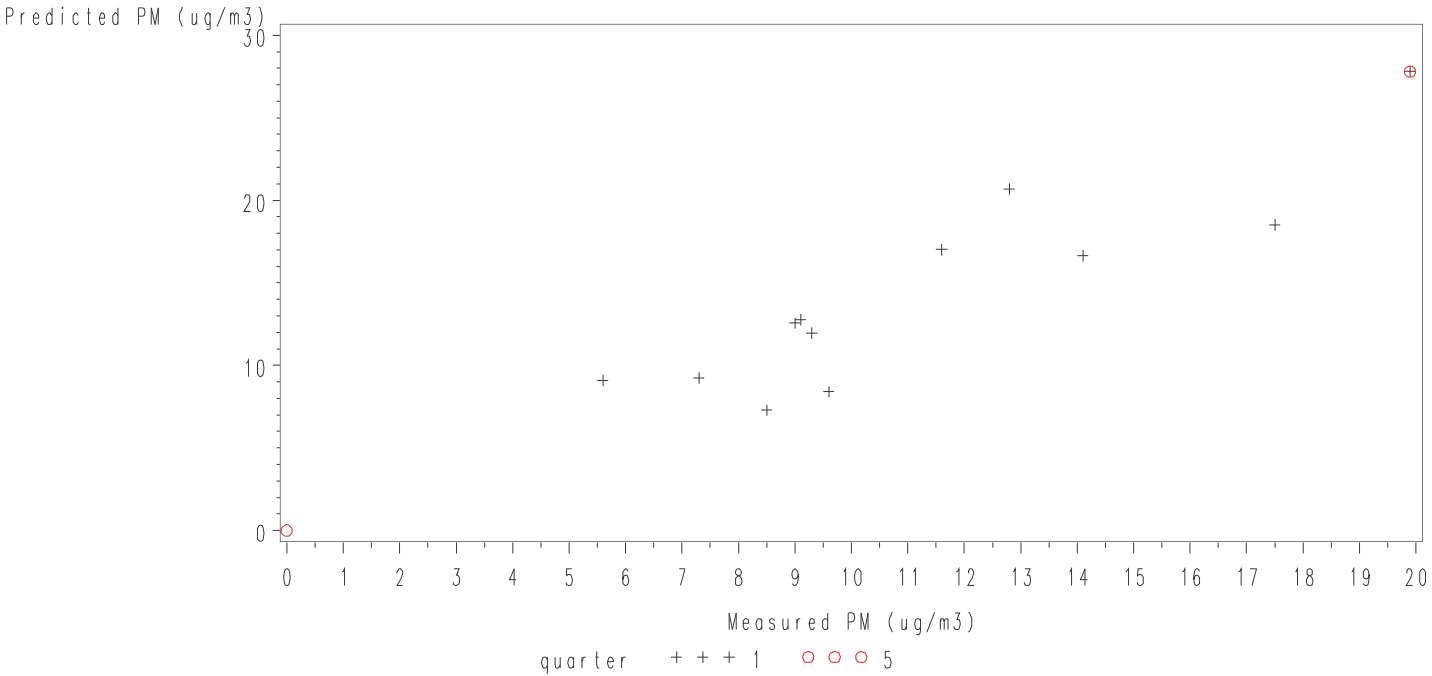


R = 0.1781
N = 53
Distance = 4.2 mi.

19MAR02:17:13:26

Site Pair: ASOS = PAH , PM = 211451004

Predicted vs Measured PM Fine
IMPROVE Model

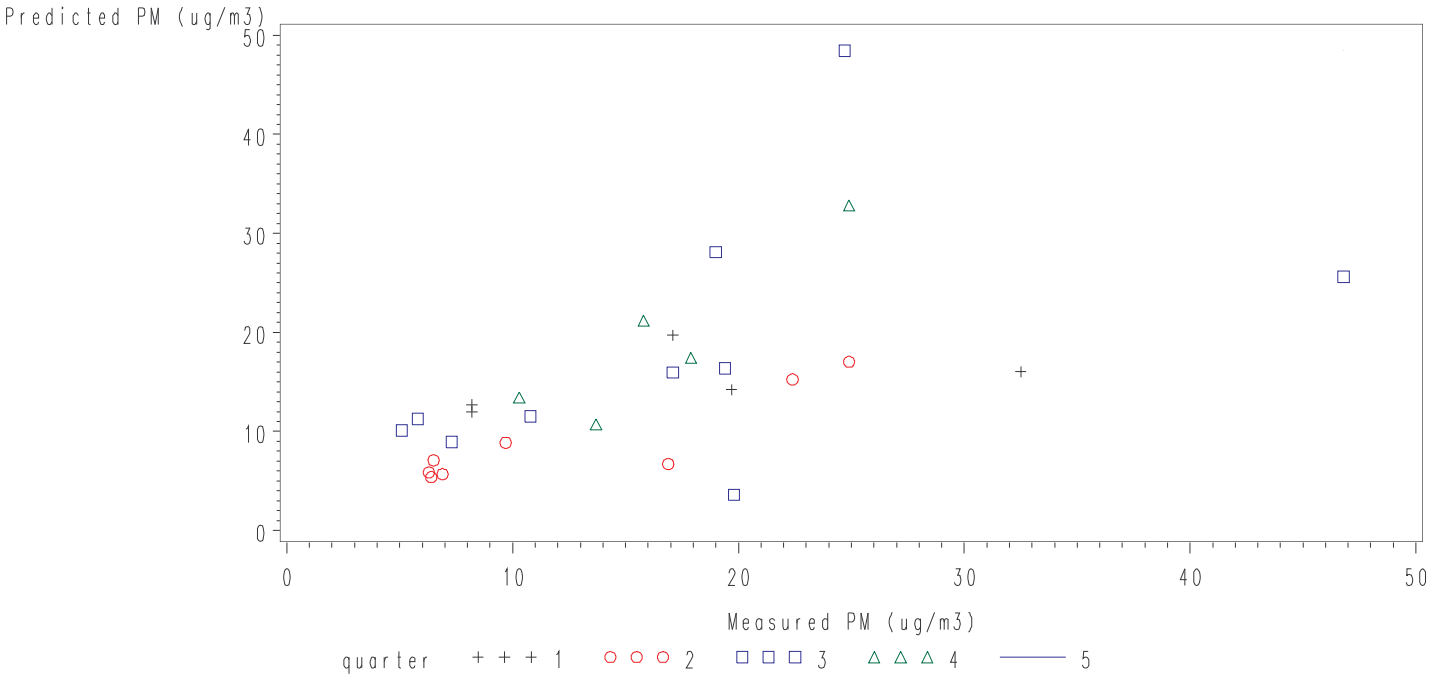


R = 0.8953
N = 12
Distance = 7.5 mi.

19MAR02:17:13:26

Site Pair: ASOS=ORD , PM=170314006

Predicted vs Measured PM Fine
IMPROVE Model

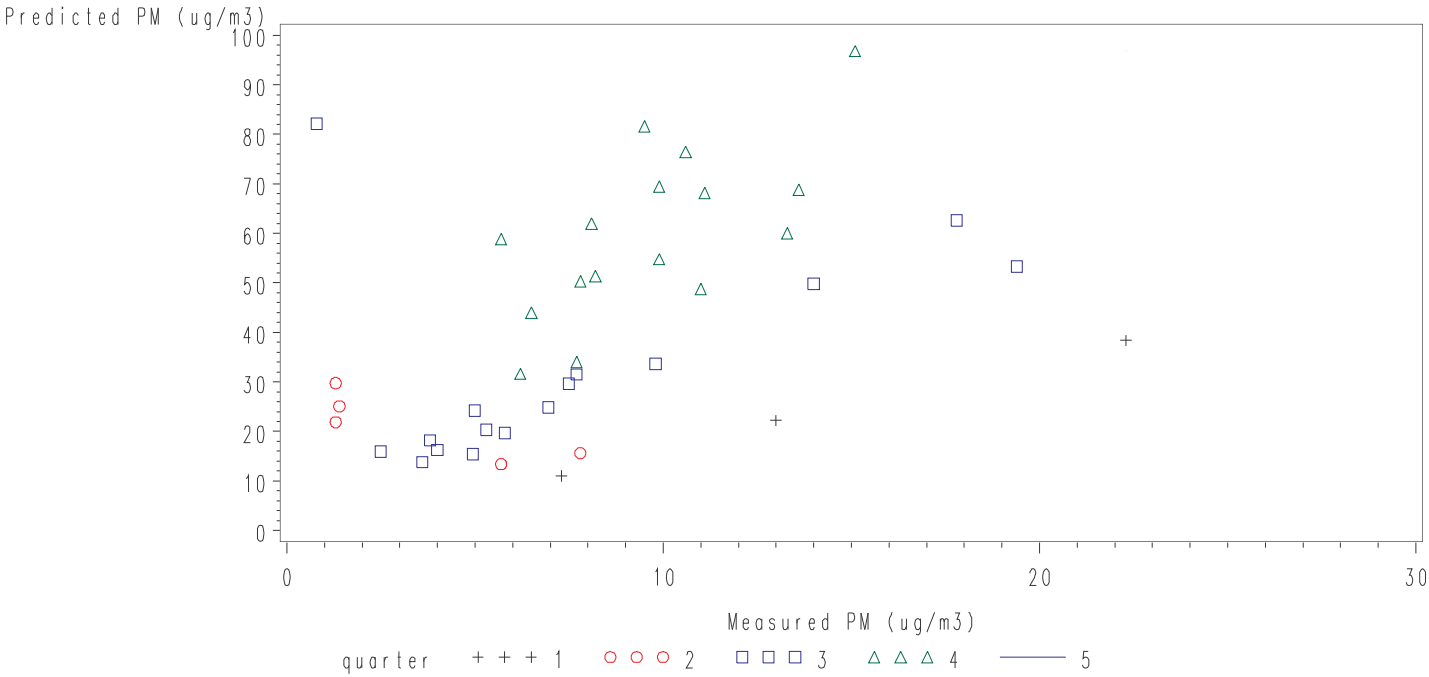


R = 0.5760
N = 28
Distance = 3.3 mi.

19MAR02:17:13:26

Site Pair: ASOS = OMA , PM = 310550019

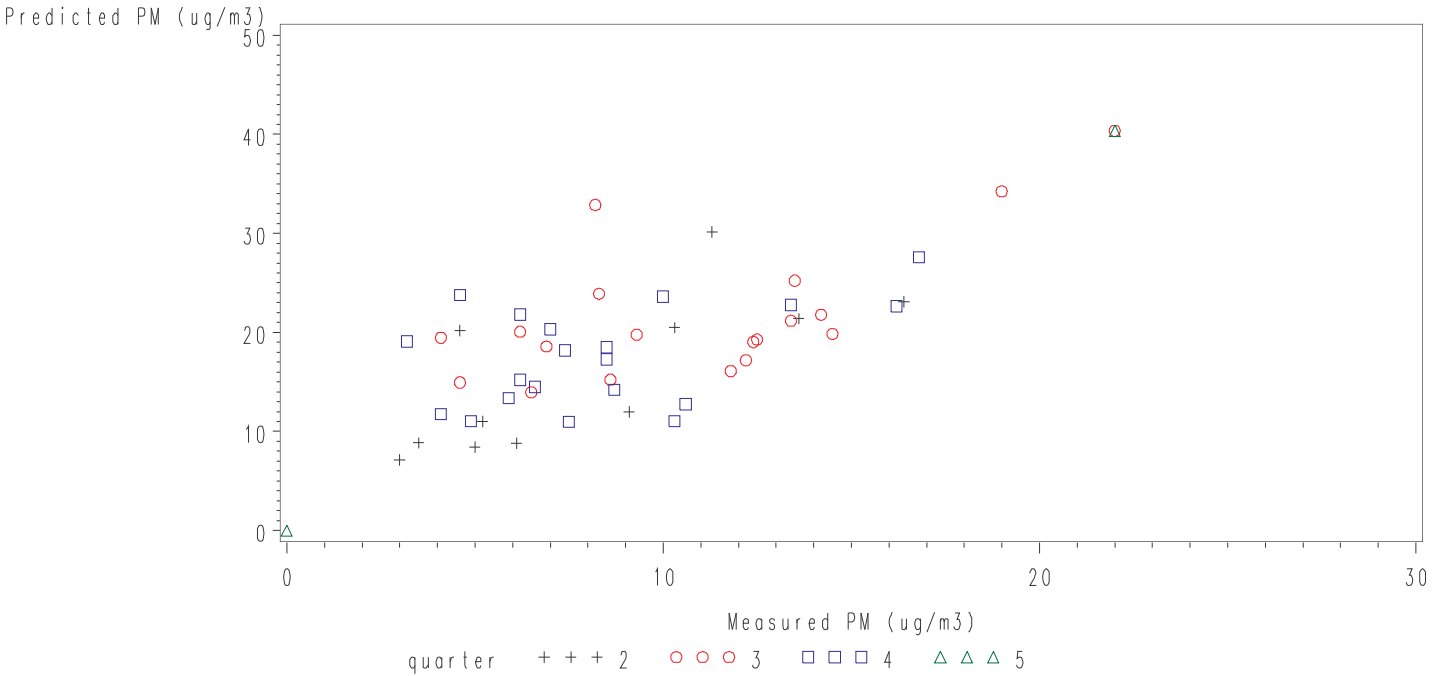
Predicted vs Measured PM Fine
IMPROVE Model



R = 0.4593
N = 40
Distance = 5.7 mi.

Site Pair: ASOS = OKC , PM = 401090038

Predicted vs Measured PM Fine
IMPROVE Model

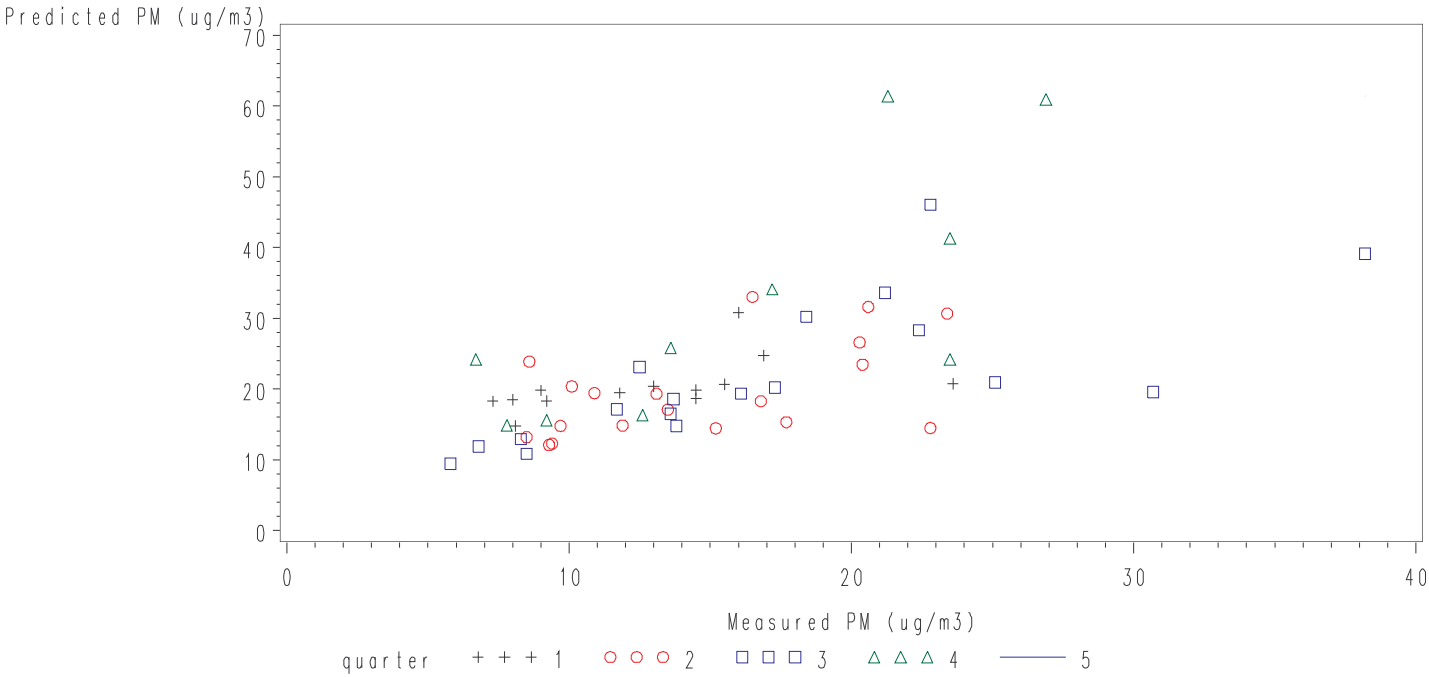


R = 0.6596
N = 50
Distance = 9.3 mi.

19MAR02:17:13:26

Site Pair: ASOS = MSY , PM = 220710012

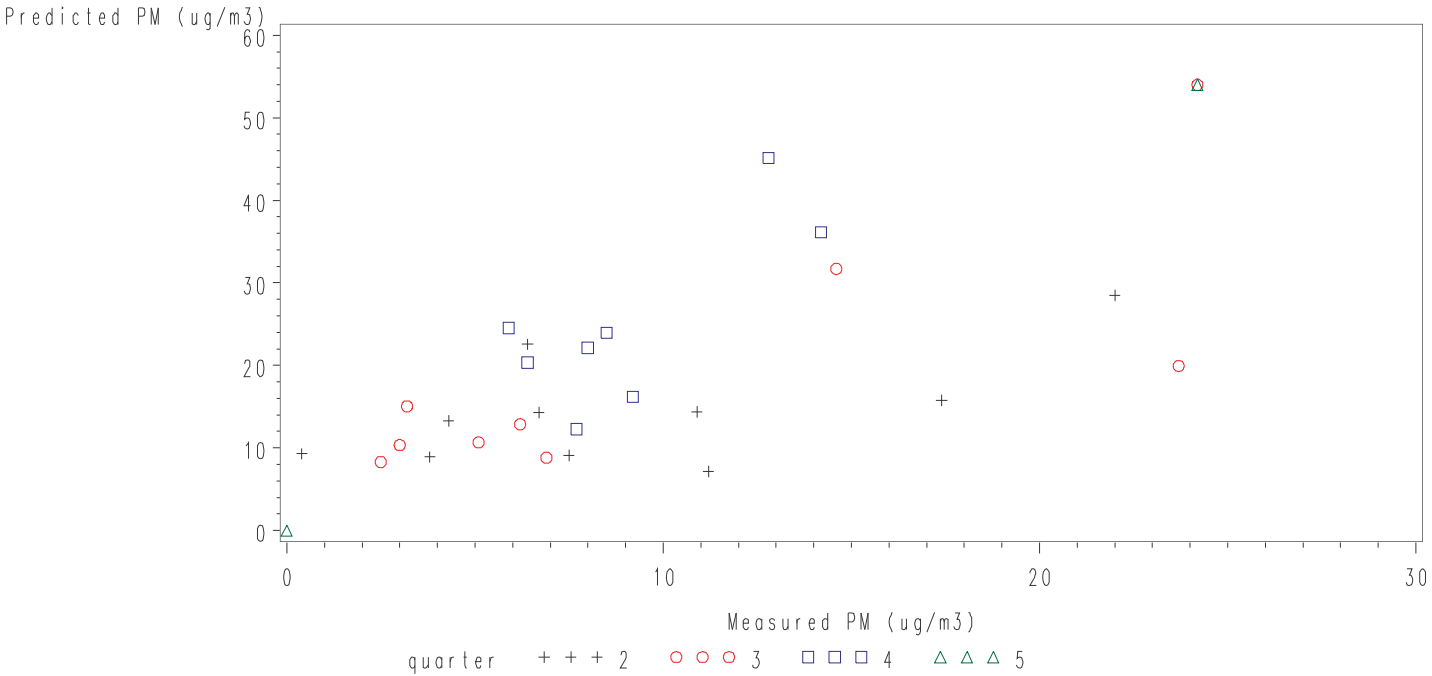
Predicted vs Measured PM Fine
IMPROVE Model



R = 0.6129
N = 60
Distance = 9.3 mi.

Site Pair: ASOS = MSP , PM = 271230872

Predicted vs Measured PM Fine
IMPROVE Model

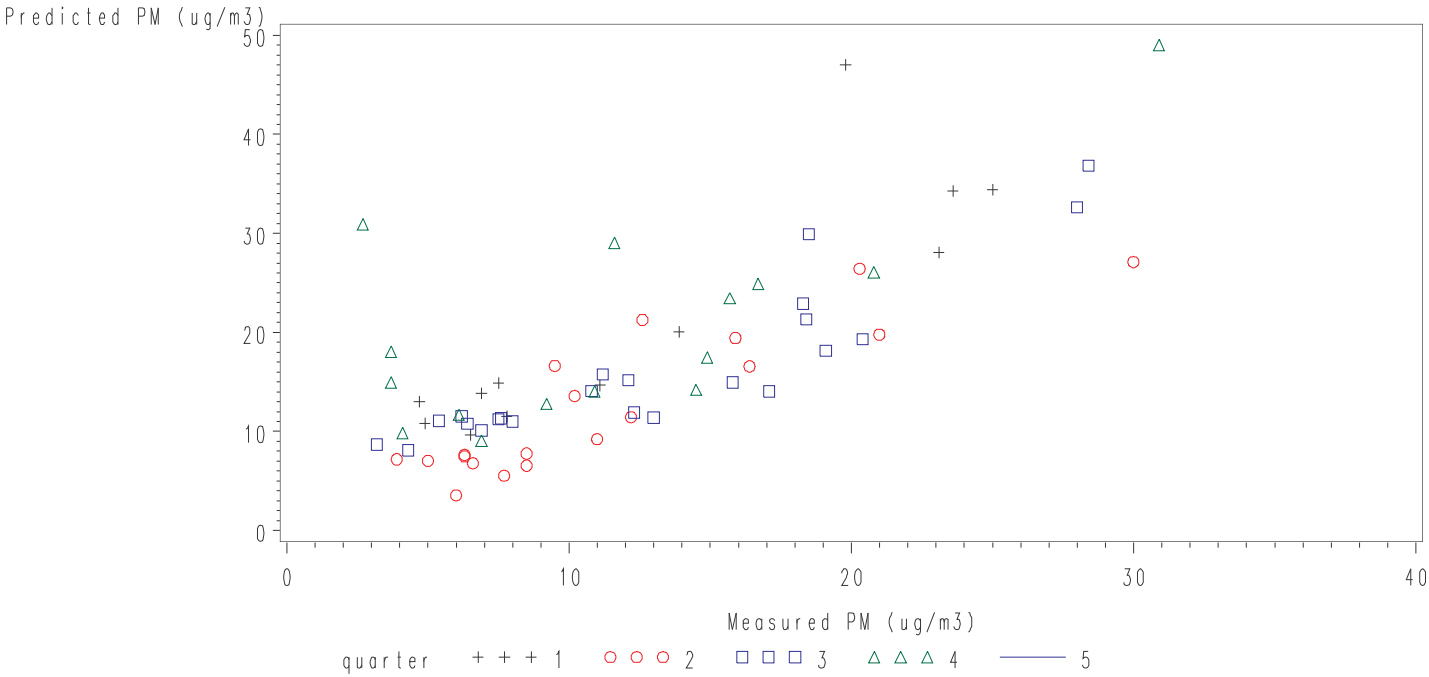


R = 0.6426
N = 27
Distance = 4.6 mi.

19MAR02:17:13:26

Site Pair: ASOS = MKE , PM = 550790099

Predicted vs Measured PM Fine
IMPROVE Model

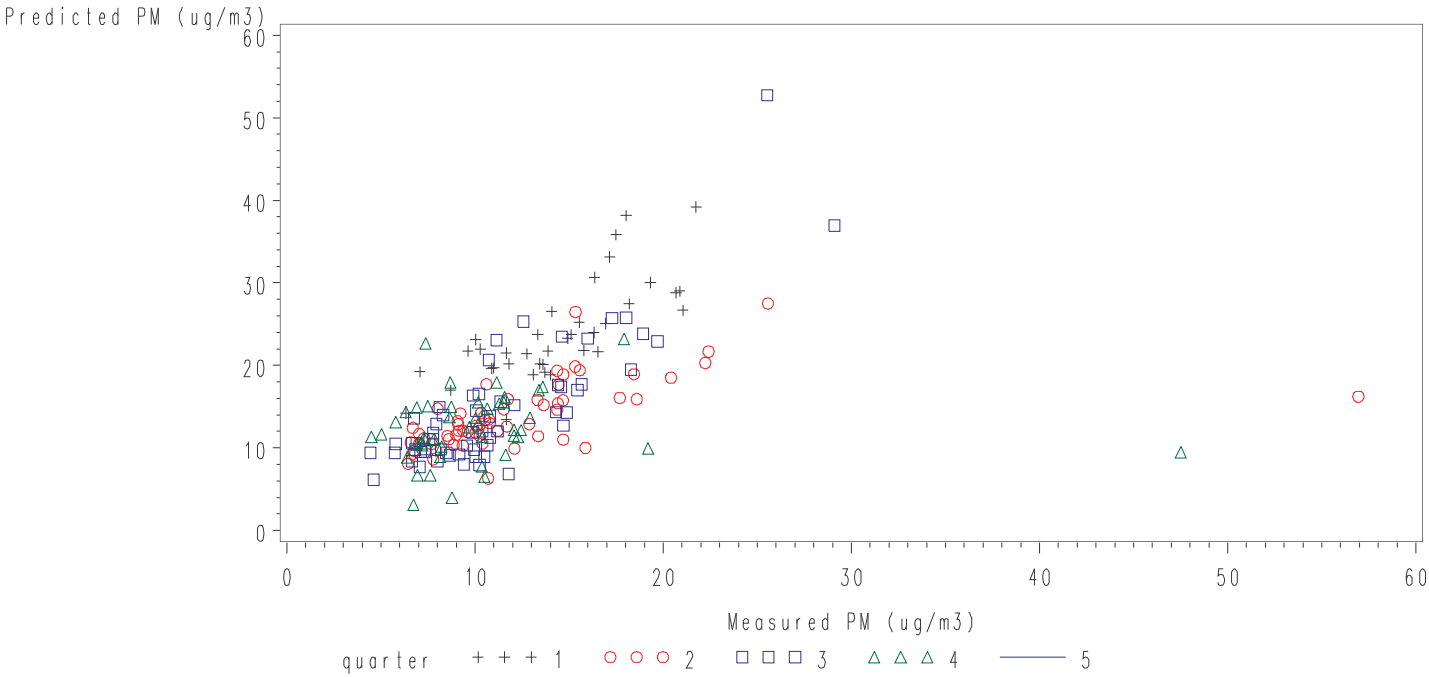


R = 0.7799
N = 69
Distance = 6.7 mi.

19MAR02:17:13:26

Site Pair: ASOS = MIA , PM = 120251016

Predicted vs Measured PM Fine
IMPROVE Model

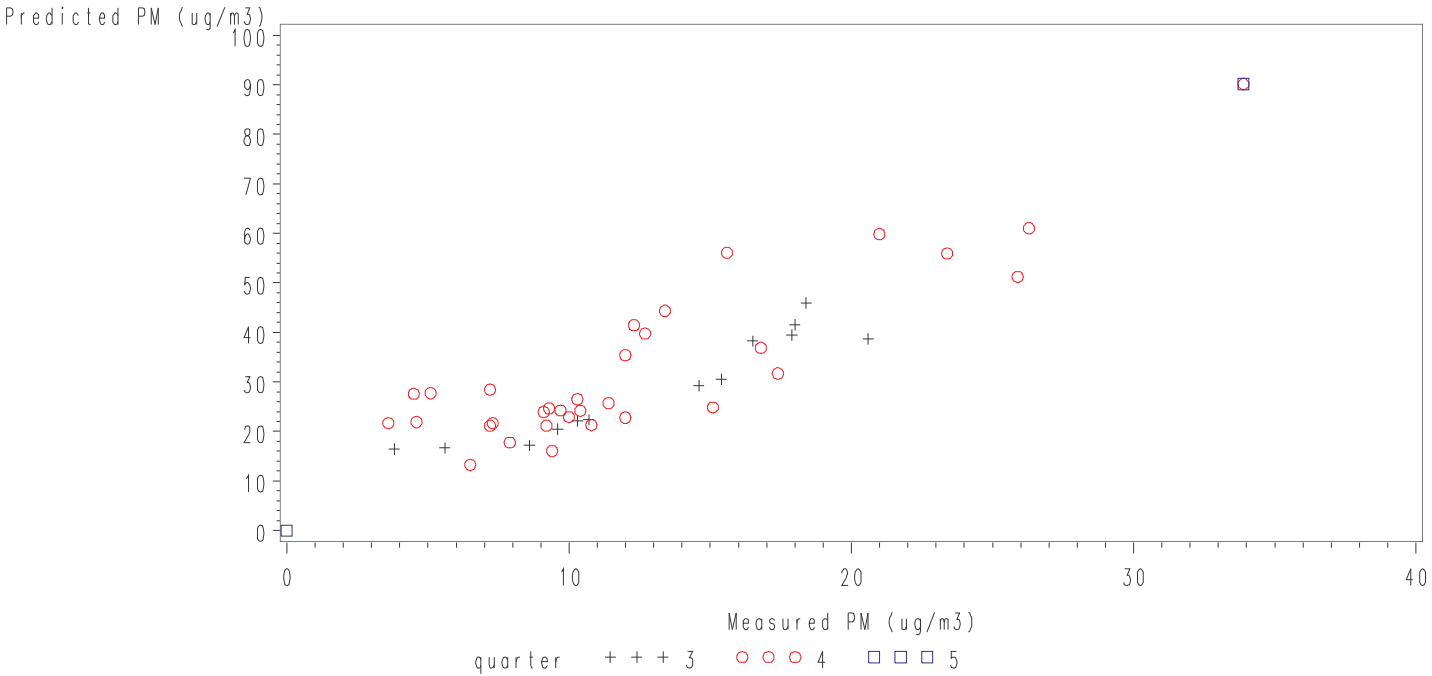


R = 0.5233
N = 206
Distance = 5.2 mi.

19MAR02:17:13:26

Site Pair: ASOS = MFR , PM = 410292129

Predicted vs Measured PM Fine
IMPROVE Model

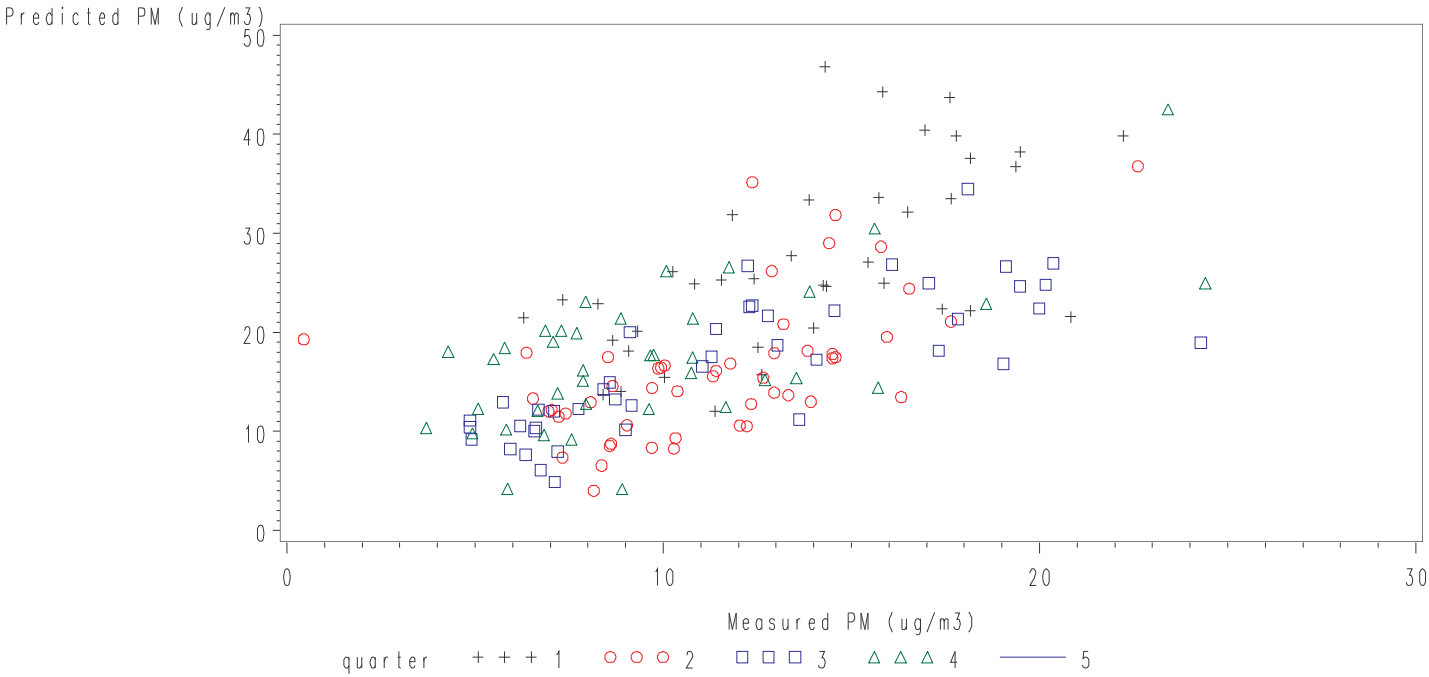


R = 0.8778
N = 46
Distance = 2.8 mi.

19MAR02:17:13:26

Site Pair: ASOS = MCO , PM = 120951004

Predicted vs Measured PM Fine
IMPROVE Model

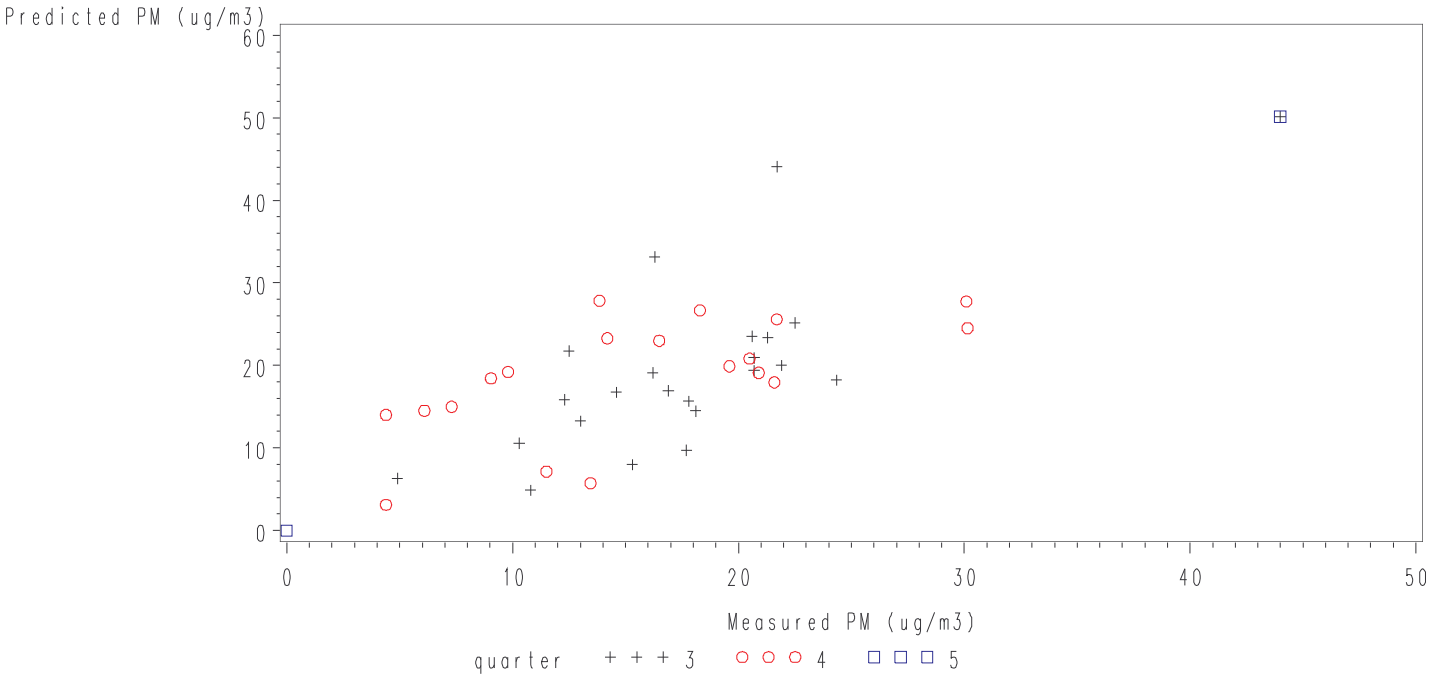


R = 0.6518
N = 172
Distance = 8.6 mi.

19MAR02:17:13:26

Site Pair: ASOS = LIT , PM = 051191008

Predicted vs Measured PM Fine
IMPROVE Model

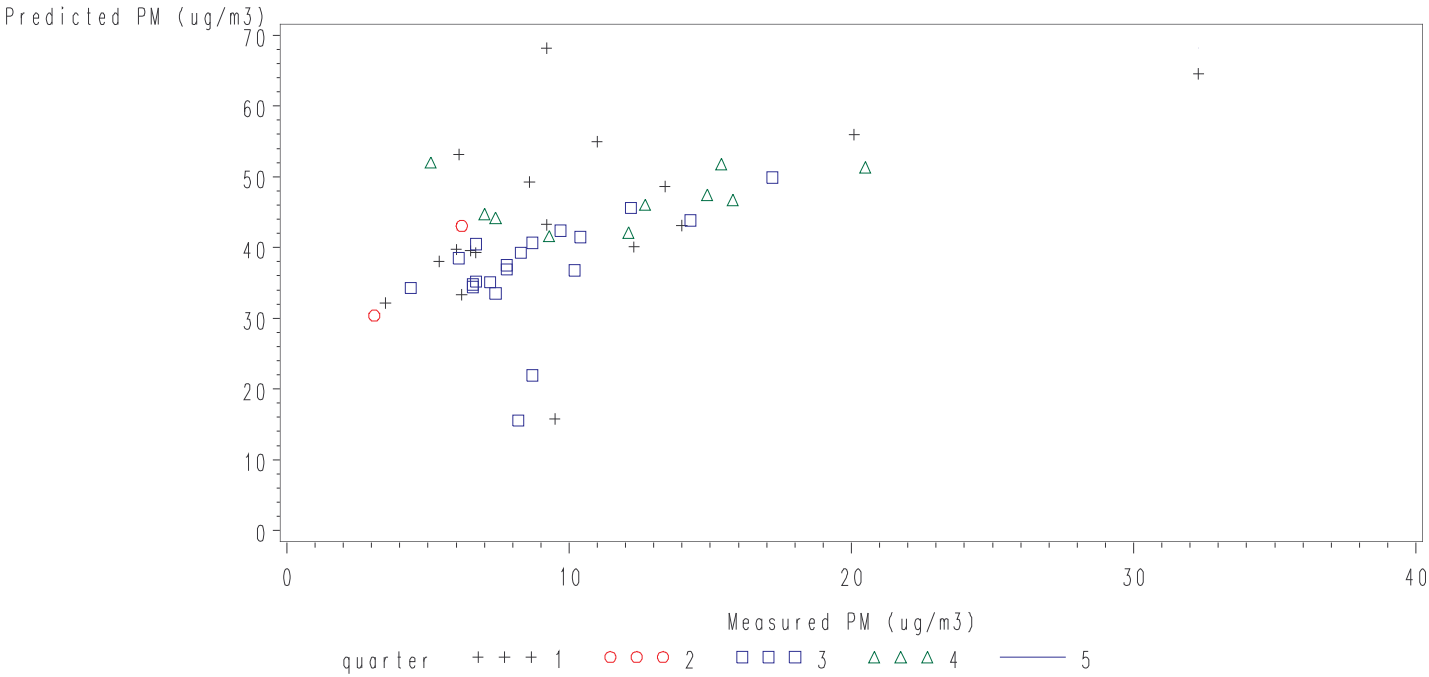


R = 0.6968
N = 42
Distance = 6.7 mi.

19MAR02:17:13:26

Site Pair: ASOS = LAS , PM = 320032002

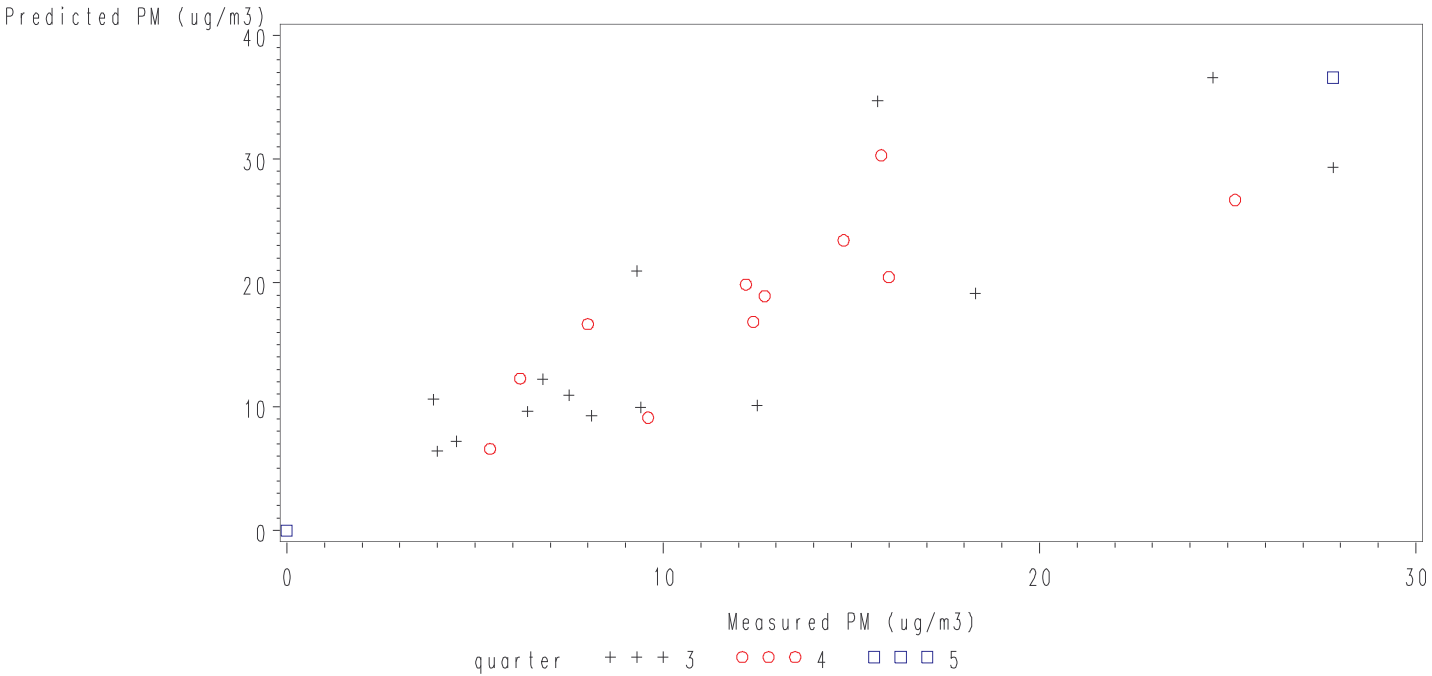
Predicted vs Measured PM Fine
IMPROVE Model



R = 0.5394
N = 49
Distance = 7.8 mi.

Site Pair: ASOS = JFK , PM = 360810097

Predicted vs Measured PM Fine
IMPROVE Model

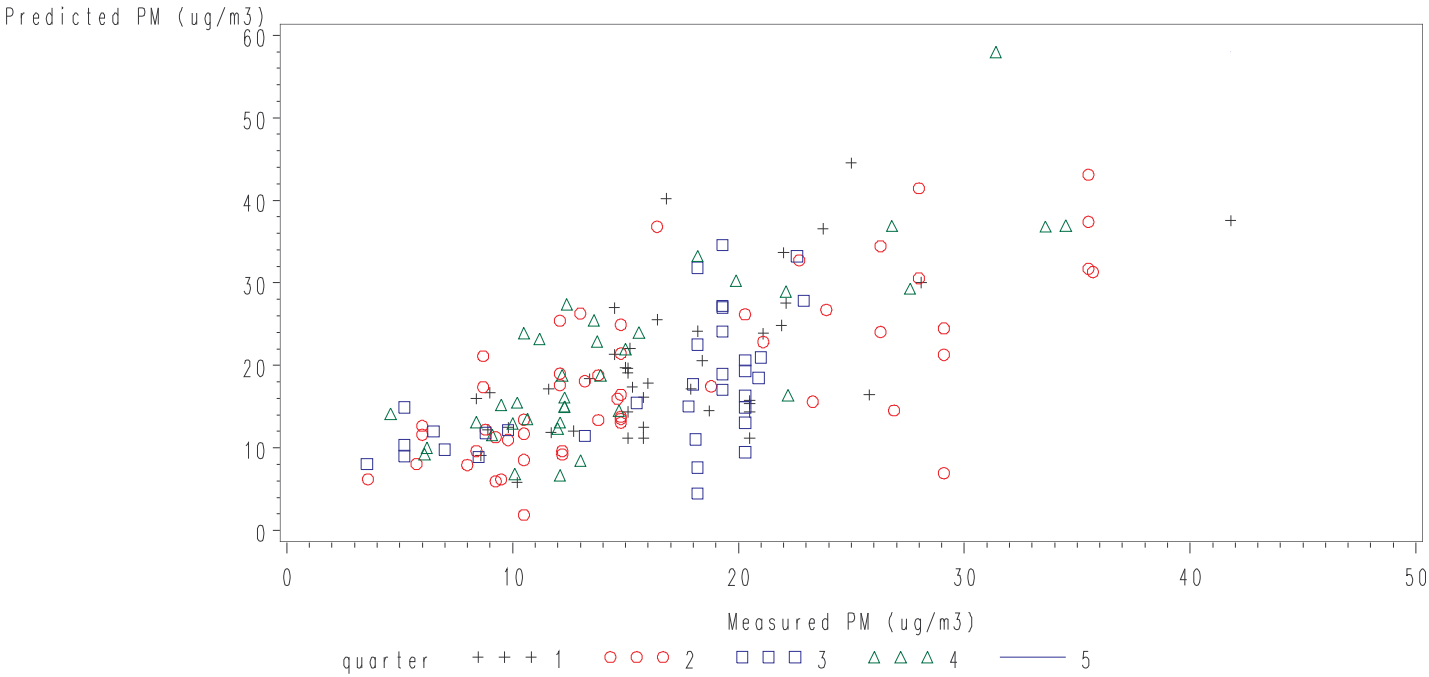


R = 0.8299
N = 25
Distance = 8.1 mi.

19MAR02:17:13:26

Site Pair: ASOS=IND , PM=180970083

Predicted vs Measured PM Fine
IMPROVE Model

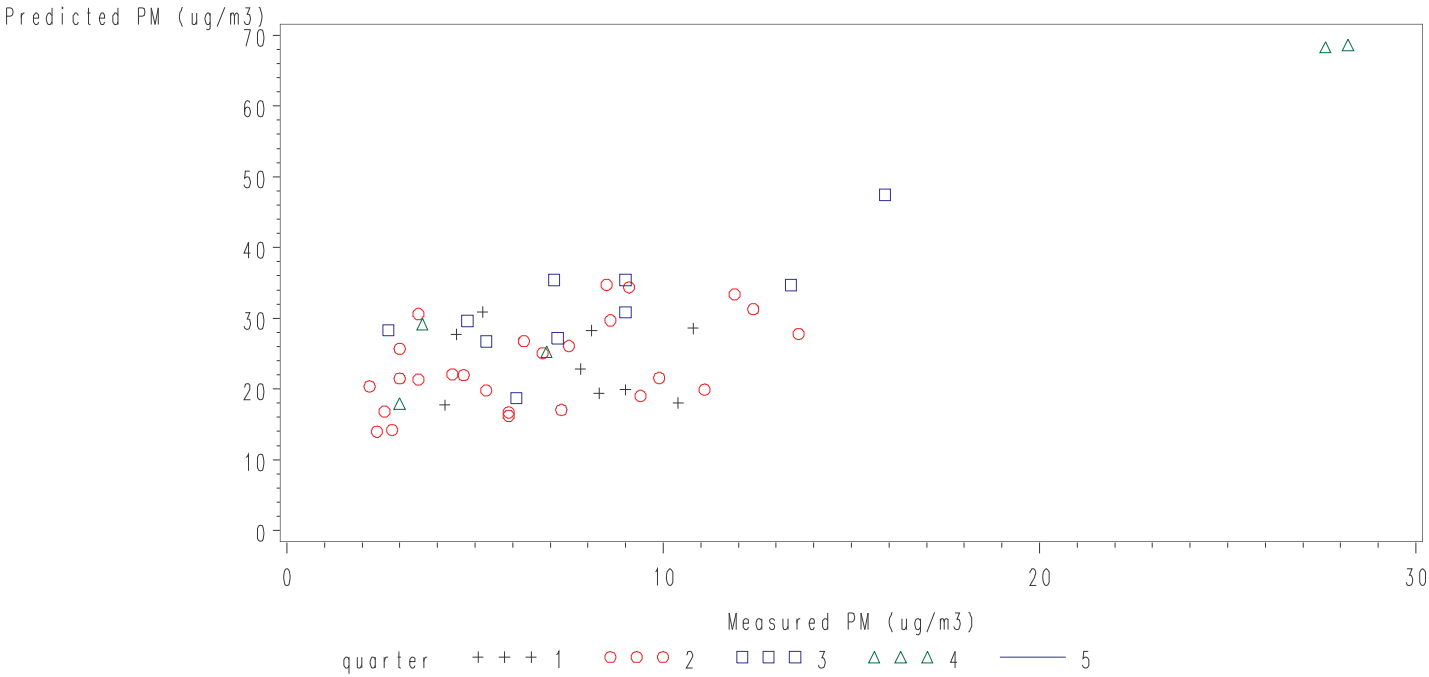


R = 0.6826
N = 164
Distance = 10 mi.

19MAR02:17:13:26

Site Pair: ASOS = GEG , PM = 530630047

Predicted vs Measured PM Fine
IMPROVE Model

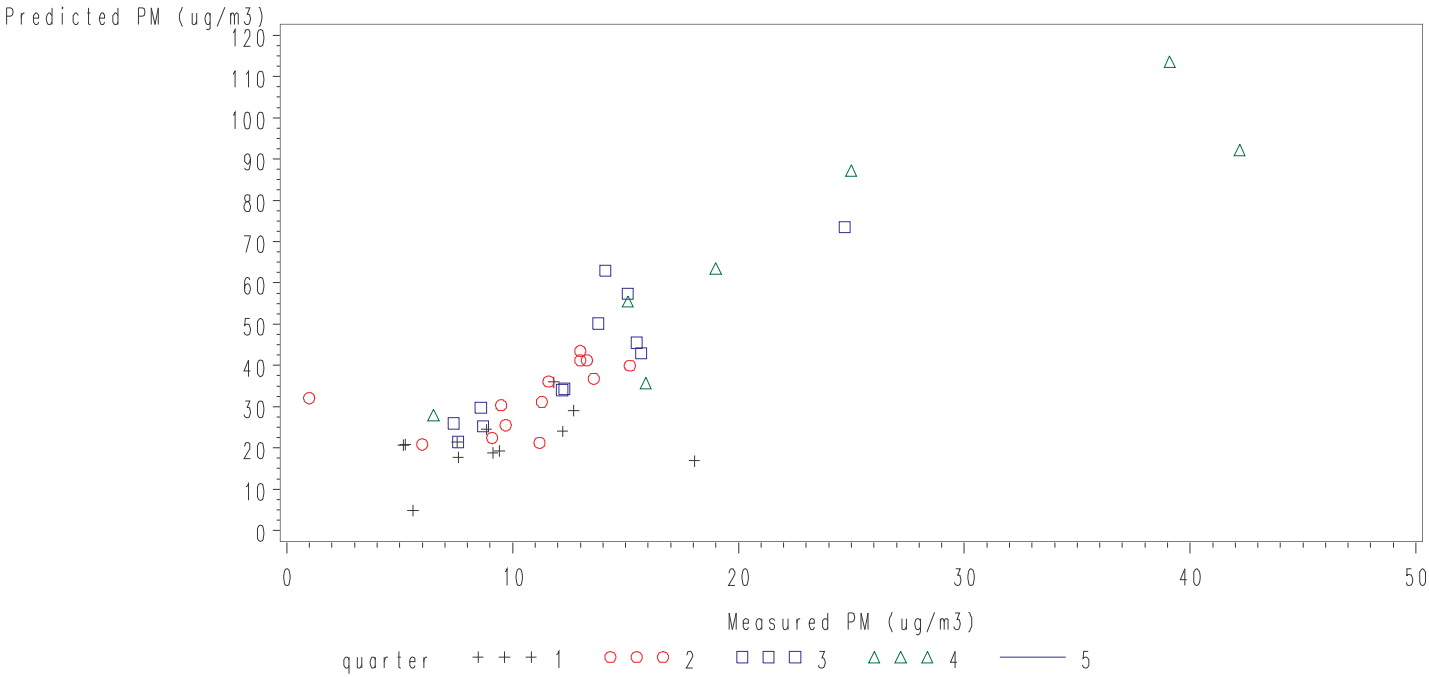


R = 0.8101
N = 50
Distance = 7.6 mi.

19MAR02:17:13:26

Site Pair: ASOS = FAT , PM = 060195001

Predicted vs Measured PM Fine
IMPROVE Model

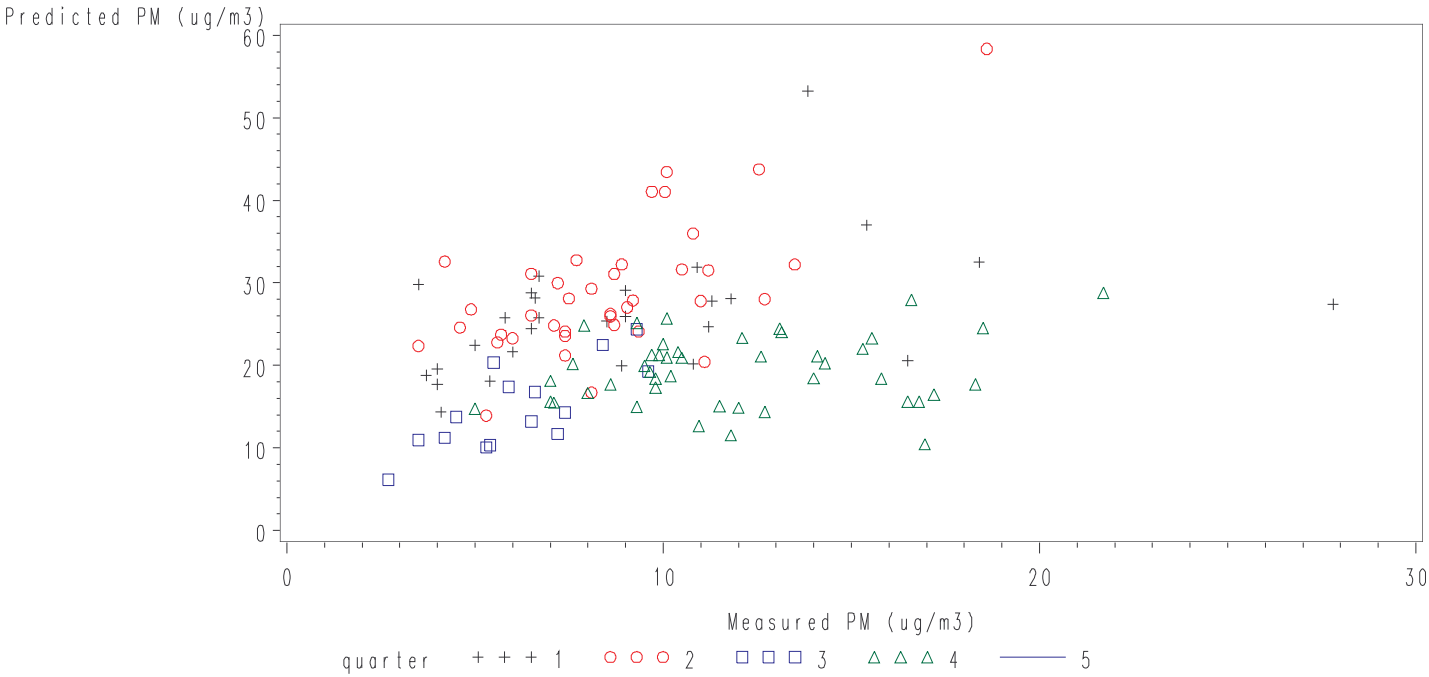


R = 0.8758
N = 44
Distance = 3.0 mi.

19MAR02:17:13:26

Site Pair: ASOS = ELP , PM = 481410044

Predicted vs Measured PM Fine
IMPROVE Model

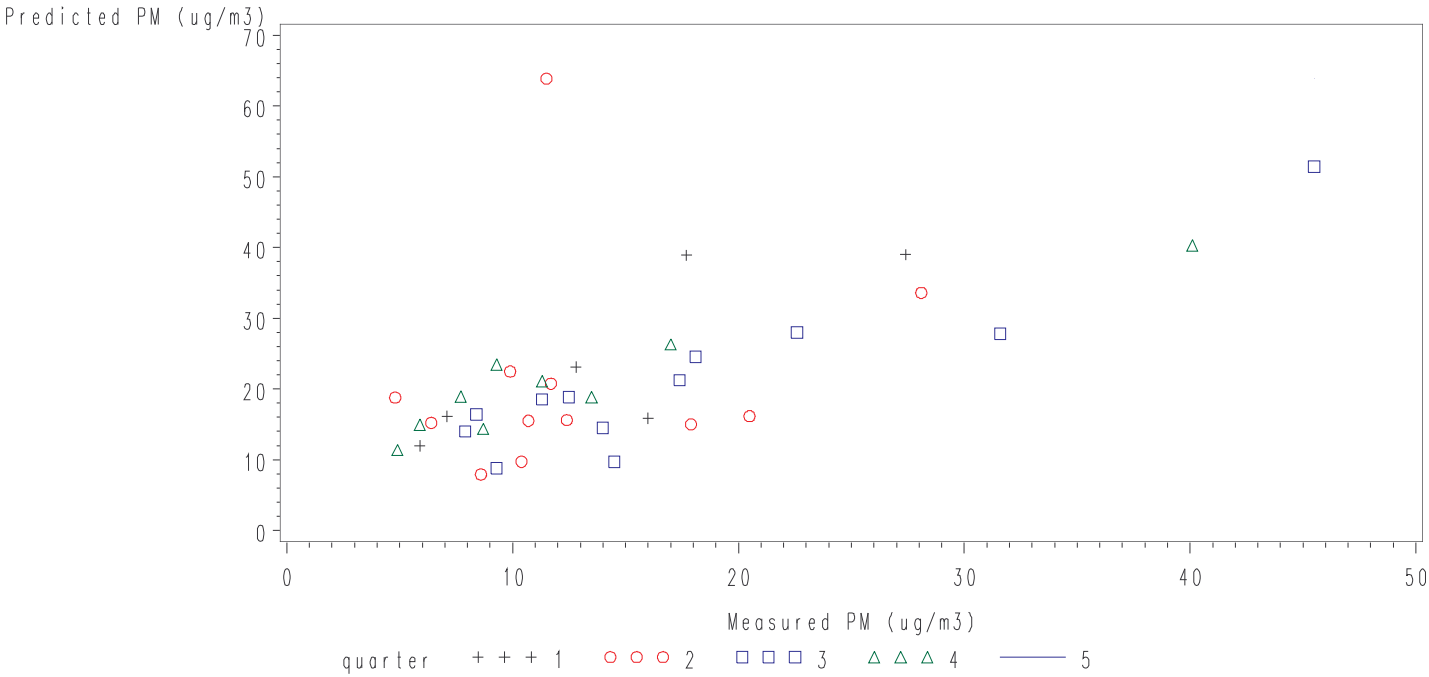


R = 0.2397
N = 127
Distance = 5.4 mi.

19MAR02:17:13:26

Site Pair: ASOS = DTW , PM = 261630036

Predicted vs Measured PM Fine
IMPROVE Model

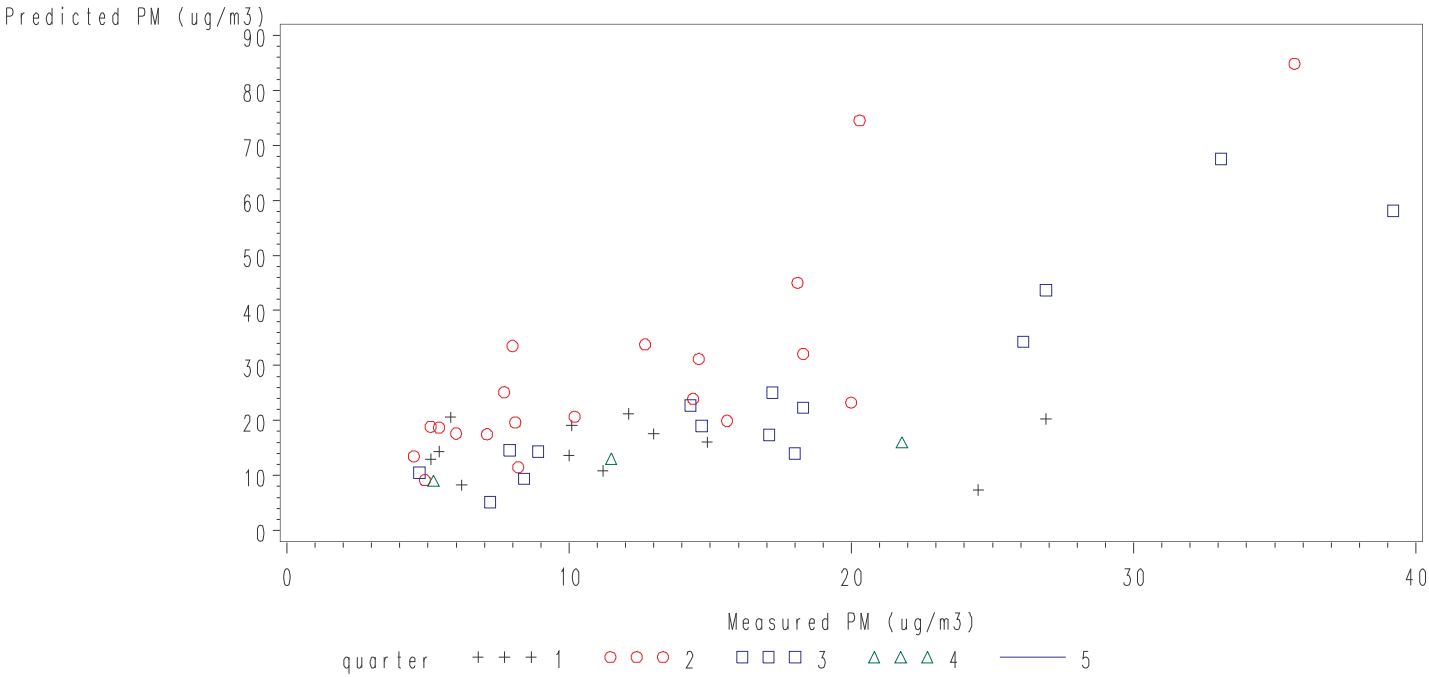


R = 0.6270
N = 39
Distance = 9.7 mi.

19MAR02:17:13:26

Site Pair: ASOS = DCA , PM = 510591004

Predicted vs Measured PM Fine
IMPROVE Model

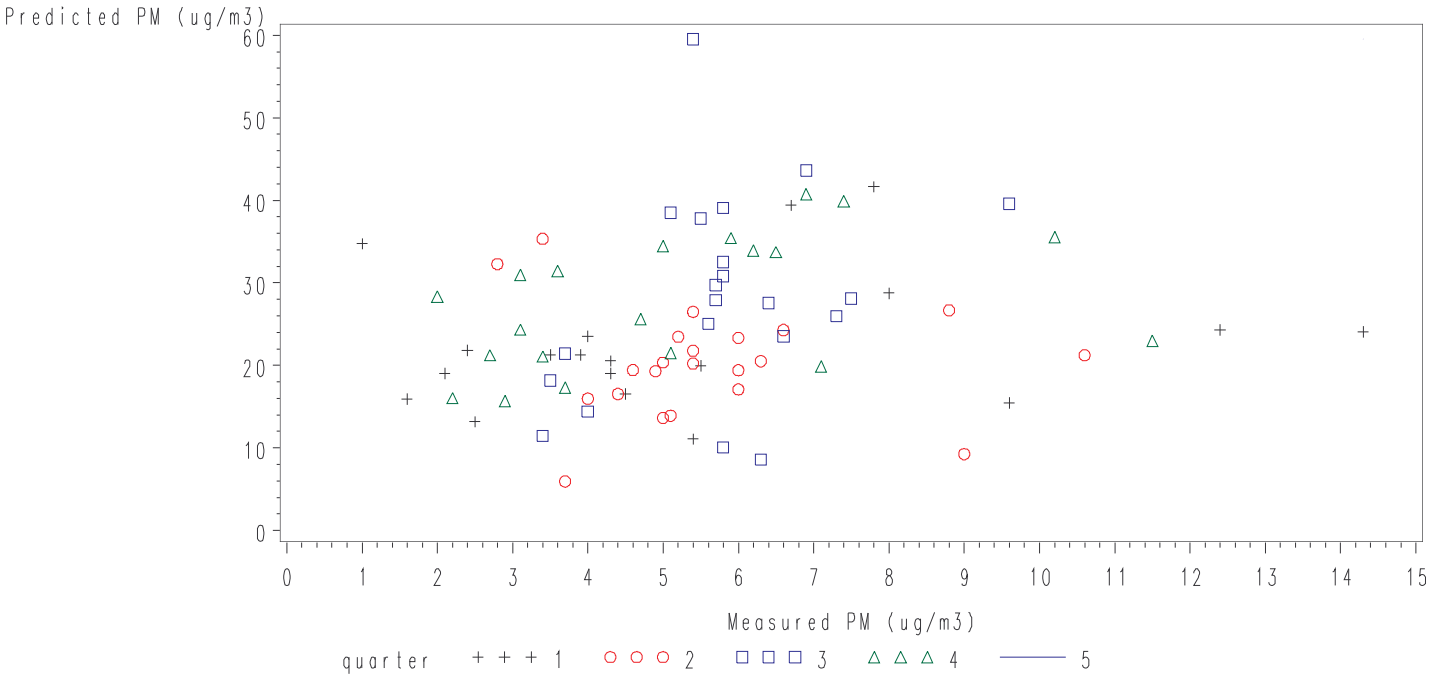


R = 0.7083
N = 50
Distance = 5.8 mi.

19MAR02:17:13:26

Site Pair: ASOS = CYS , PM = 560210001

Predicted vs Measured PM Fine
IMPROVE Model

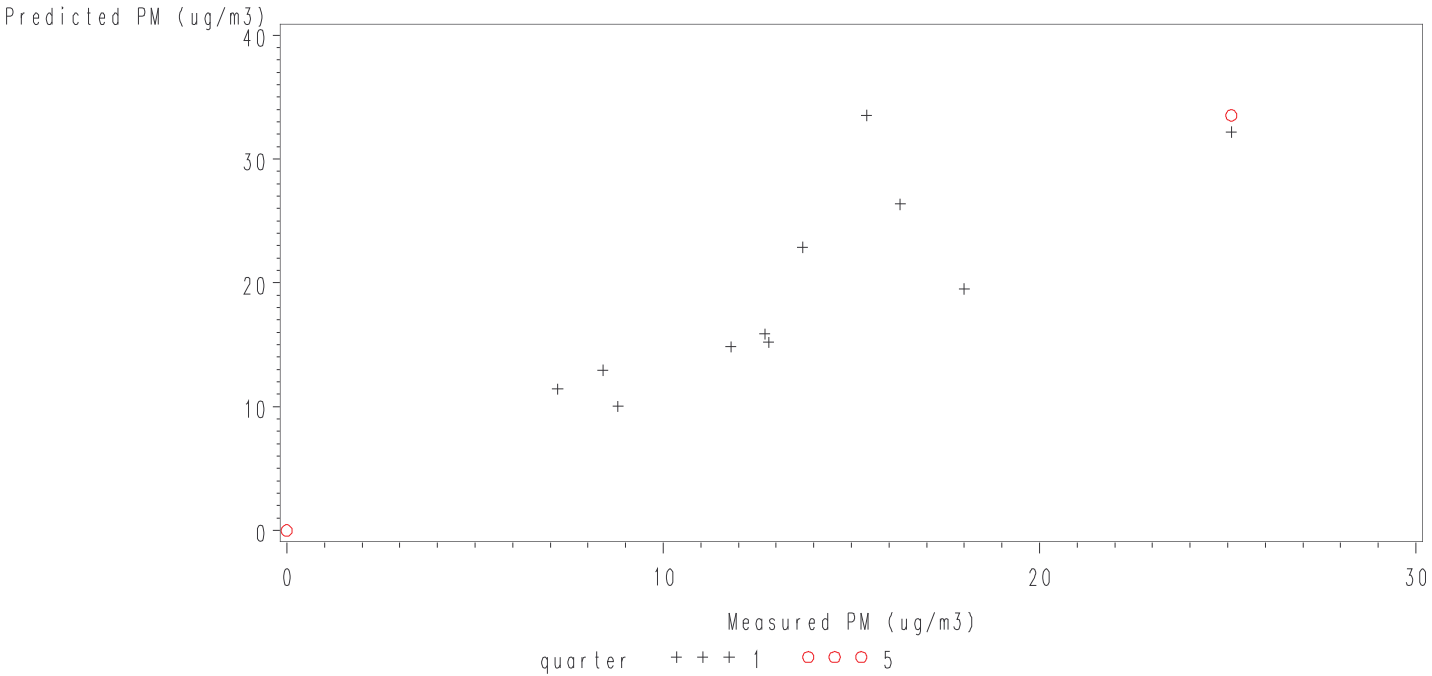


R = 0.1878
N = 82
Distance = 1.1 mi.

19MAR02:17:13:26

Site Pair: ASOS = CVG , PM = 211170007

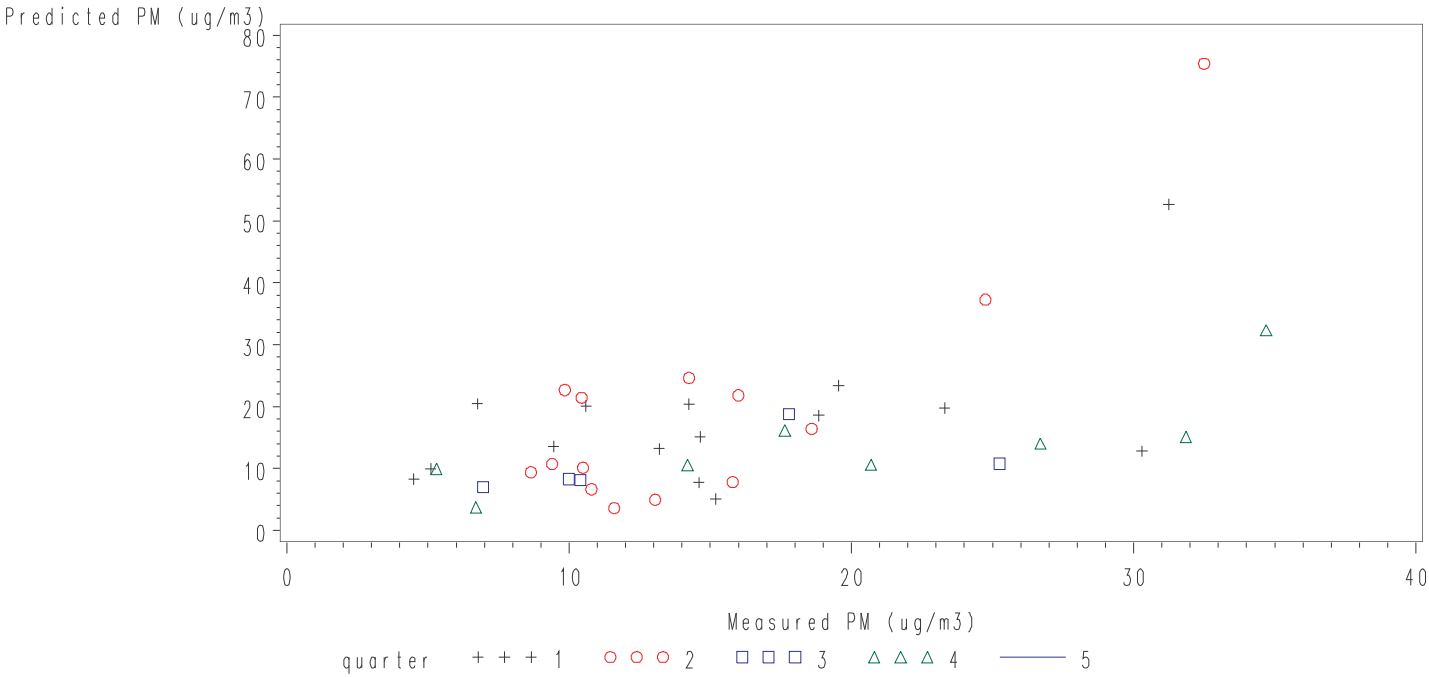
Predicted vs Measured PM Fine
IMPROVE Model



R = 0.8108
N = 11
Distance = 7.6 mi.

Site Pair: ASOS = CRW , PM = 540391005

Predicted vs Measured PM Fine
IMPROVE Model

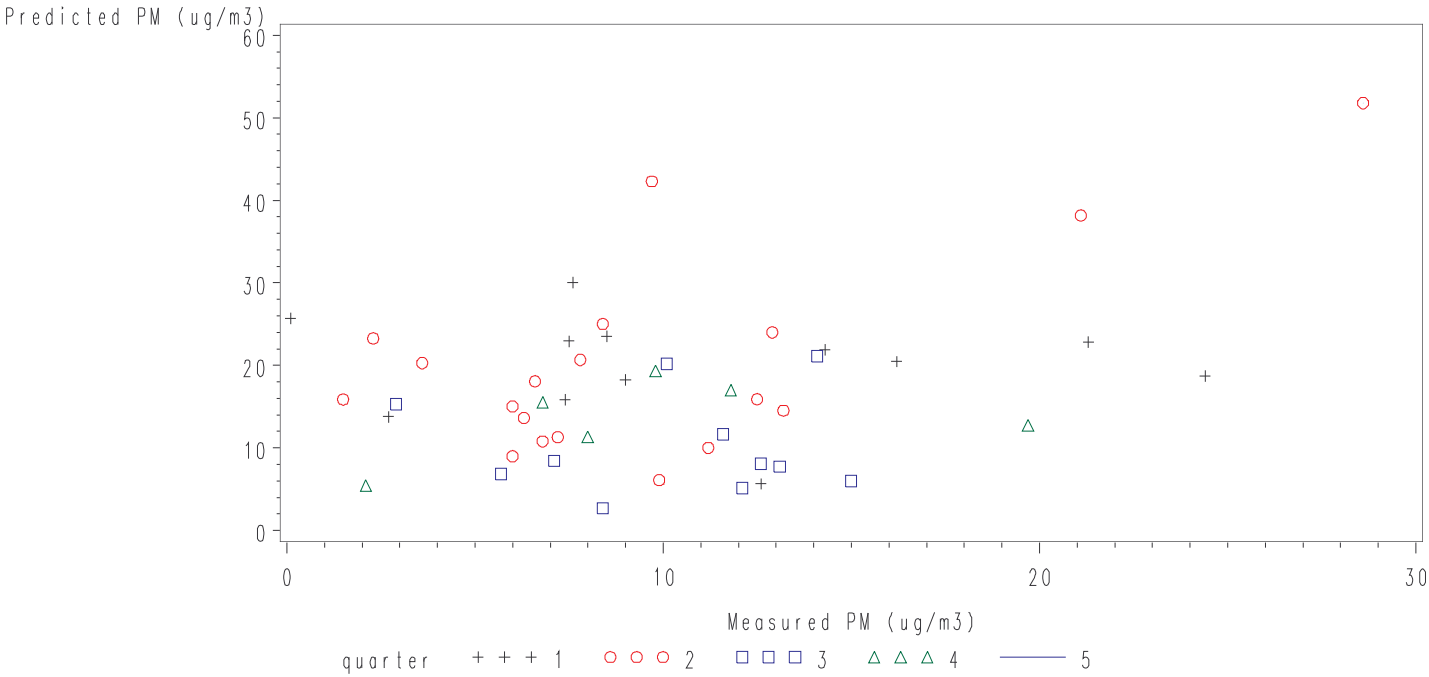


R = 0.5869
N = 42
Distance = 5.5 mi.

19MAR02:17:13:26

Site Pair: ASOS = CON , PM = 330130003

Predicted vs Measured PM Fine
IMPROVE Model

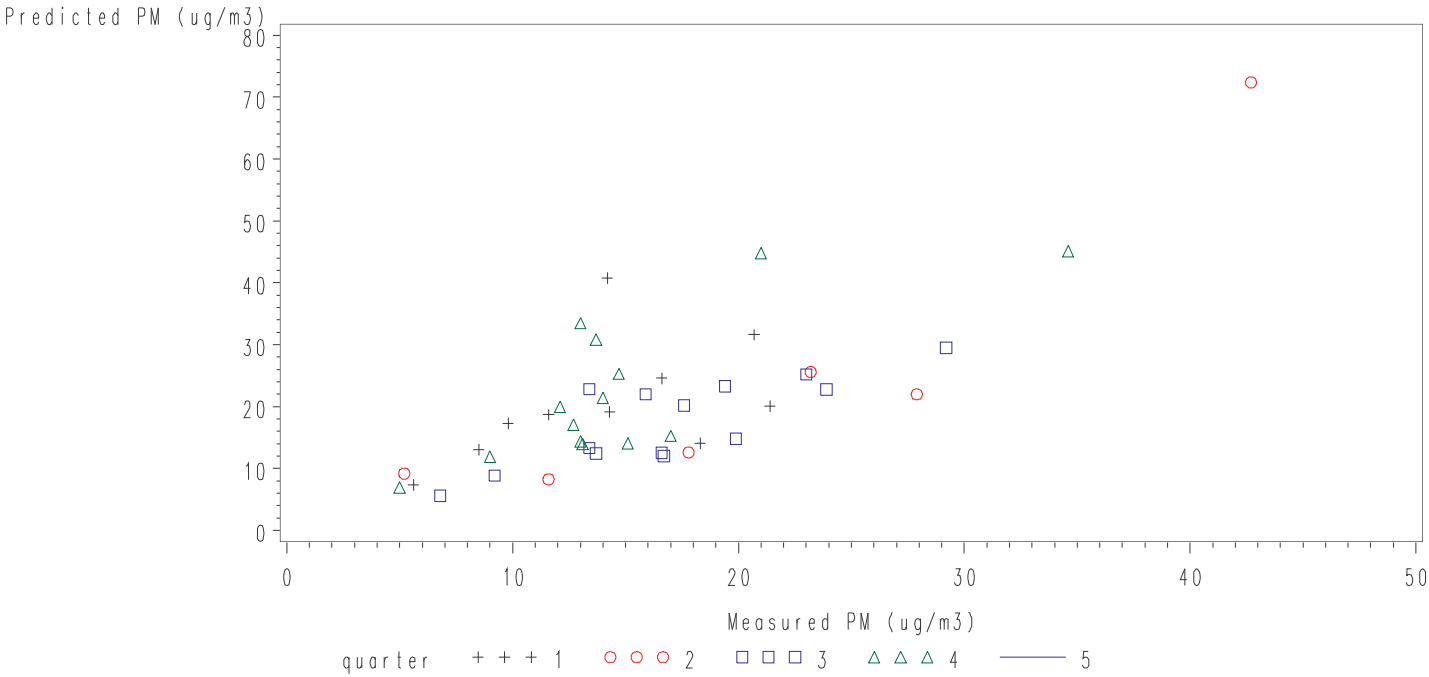


R = 0.3396
N = 48
Distance = 1.8 mi.

19MAR02:17:13:26

Site Pair: ASOS = CMH , PM = 390490081

Predicted vs Measured PM Fine
IMPROVE Model

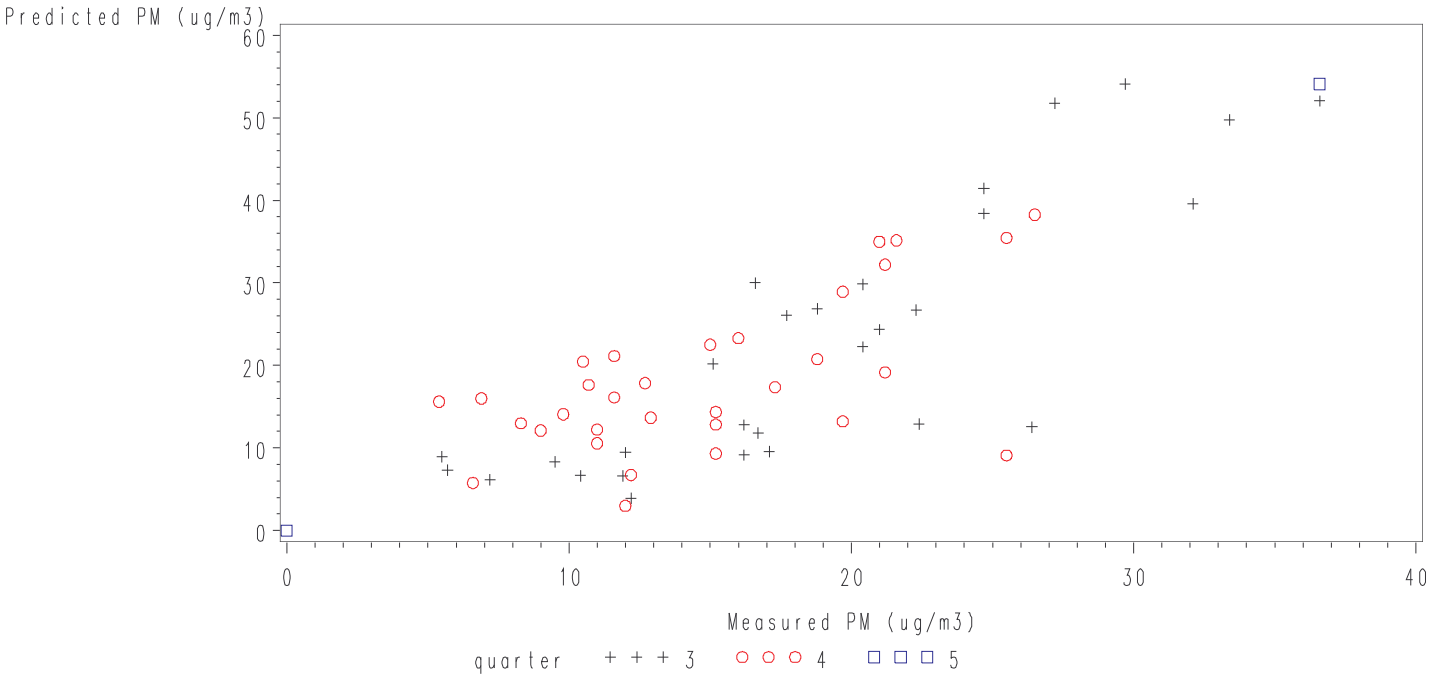


R = 0.7512
N = 44
Distance = 7.2 mi.

19MAR02:17:13:26

Site Pair: ASOS = CLT , PM = 371190041

Predicted vs Measured PM Fine
IMPROVE Model

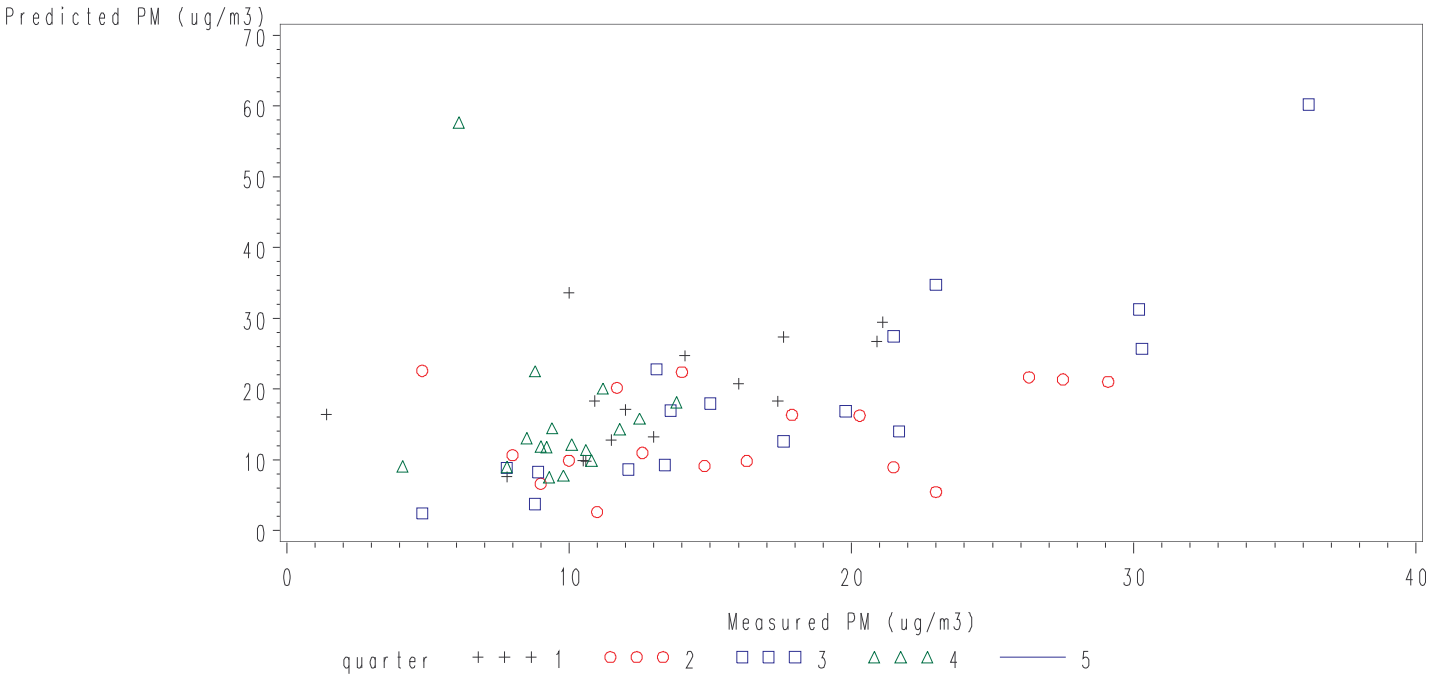


R = 0.7829
N = 61
Distance = 9.2 mi.

19MAR02:17:13:26

Site Pair: ASOS = CLE , PM = 390351002

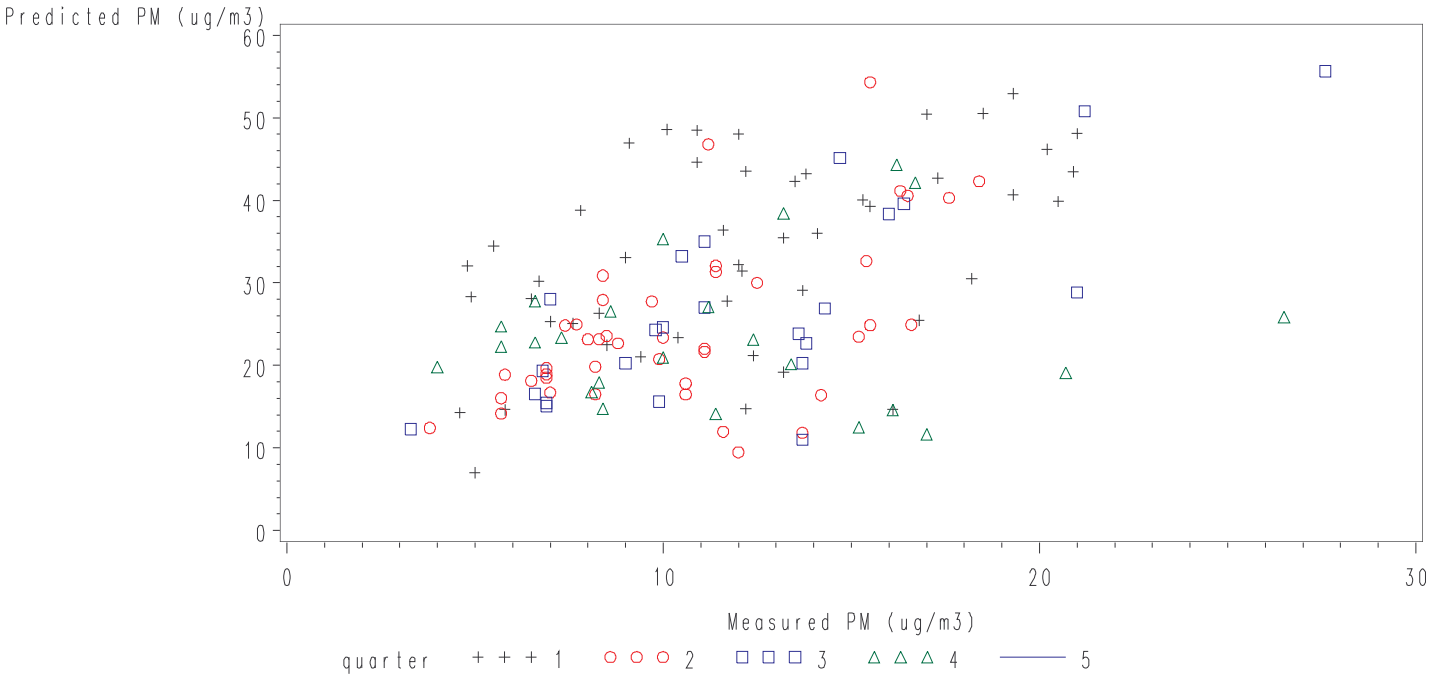
Predicted vs Measured PM Fine
IMPROVE Model



R = 0.4585
N = 66
Distance = 1.9 mi.

Site Pair: ASOS = CHS , PM = 450190049

Predicted vs Measured PM Fine
IMPROVE Model

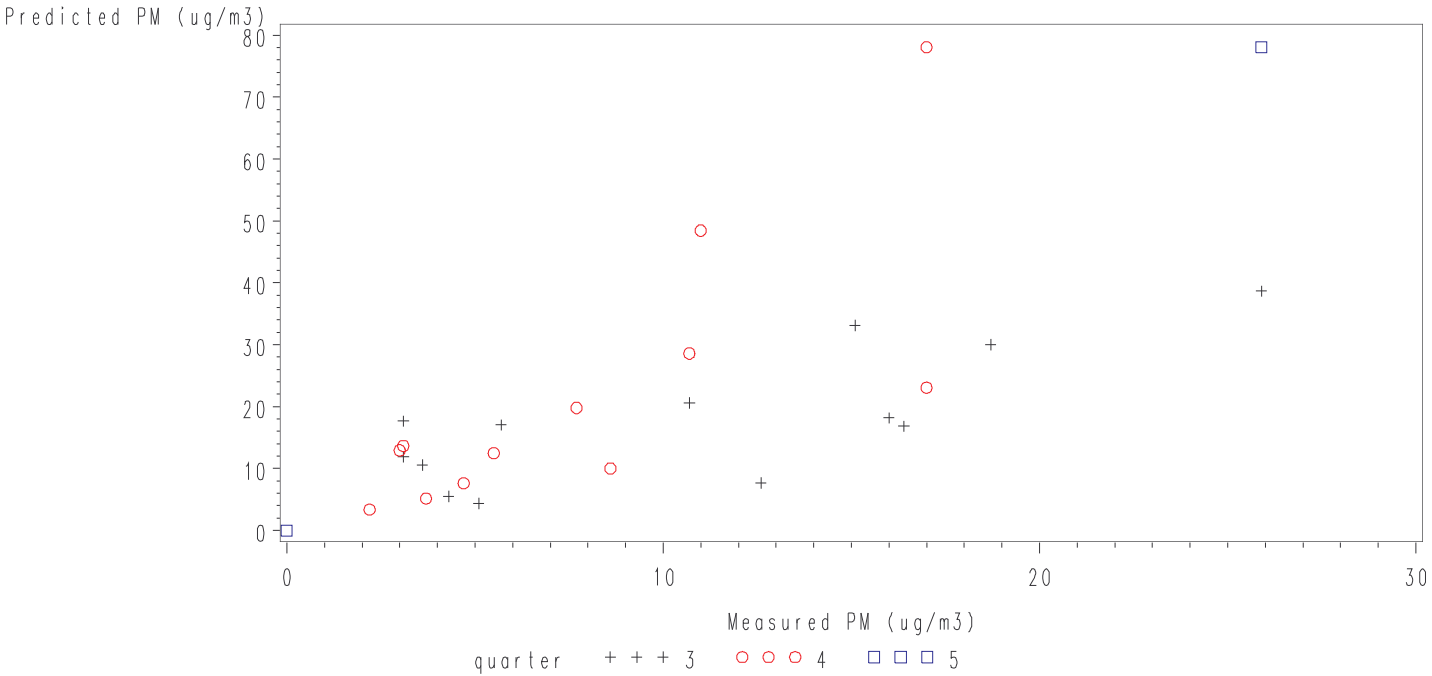


R = 0.5075
N = 139
Distance = 8.8 mi.

19MAR02:17:13:26

Site Pair: ASOS = BTV , PM = 500070012

Predicted vs Measured PM Fine
IMPROVE Model

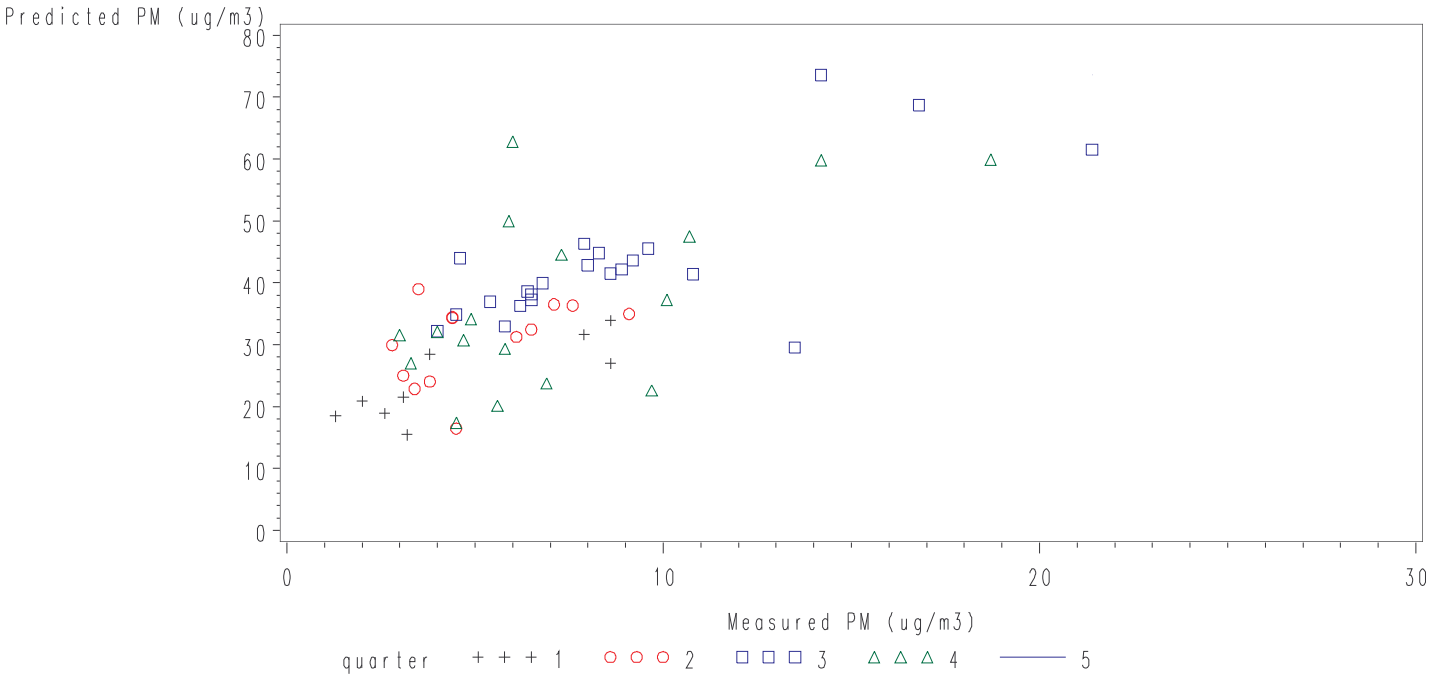


R = 0.6199
N = 25
Distance = 3.2 mi.

19MAR02:17:13:26

Site Pair: ASOS=BOI , PM=160010017

Predicted vs Measured PM Fine
IMPROVE Model

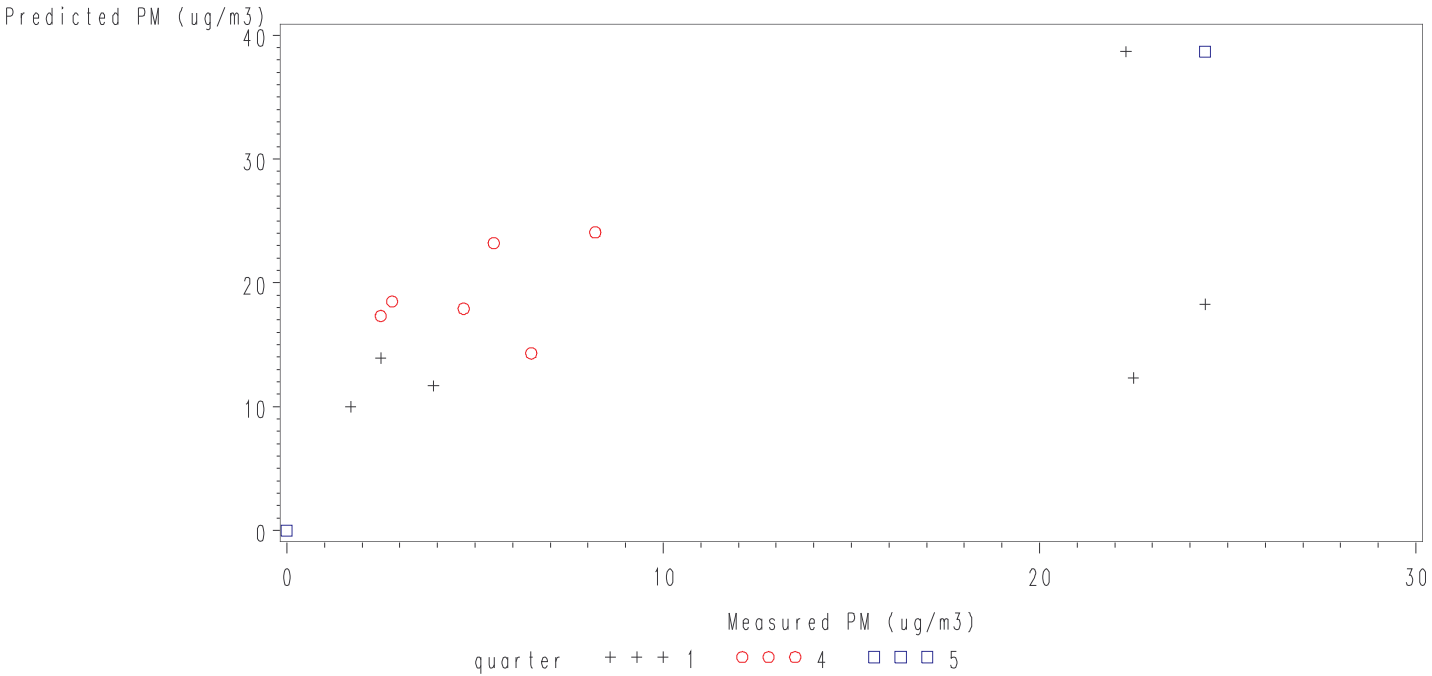


R = 0.7203
N = 61
Distance = 2.4 mi.

19MAR02:17:13:26

Site Pair: ASOS = BIS , PM = 380150003

Predicted vs Measured PM Fine
IMPROVE Model

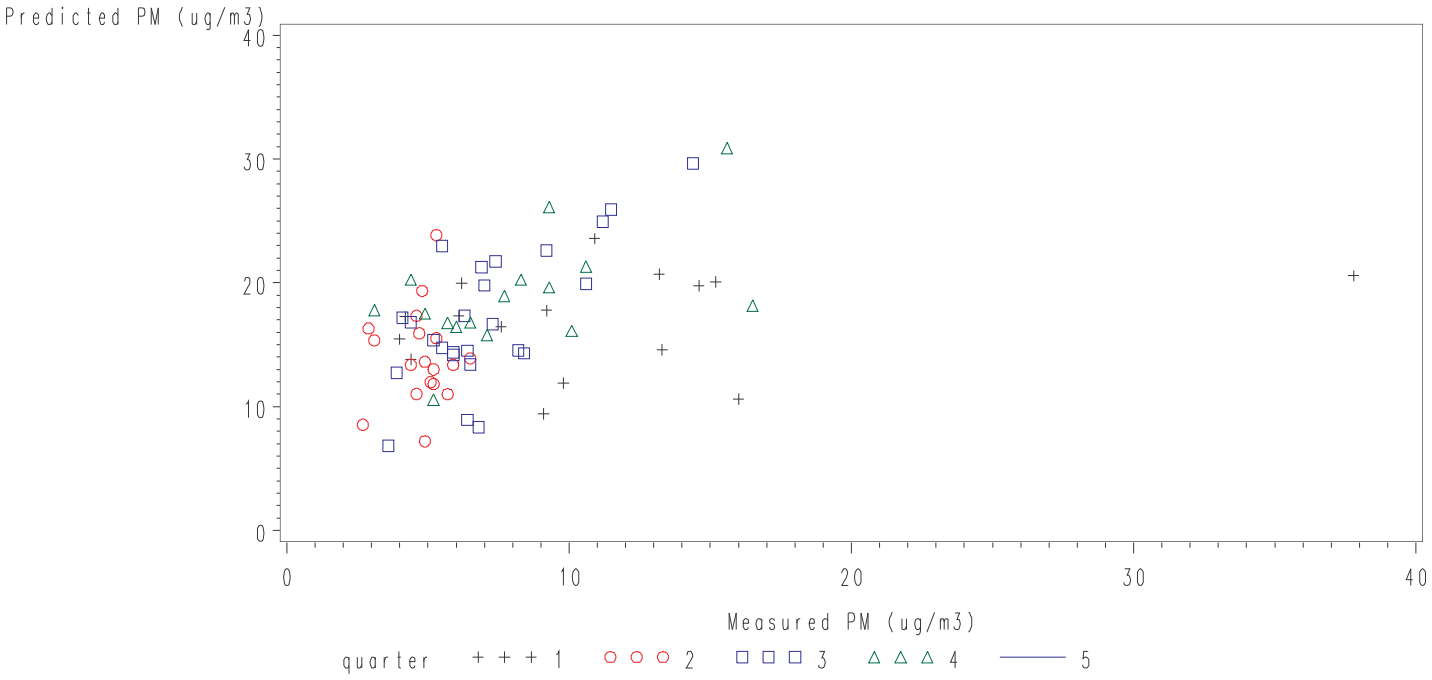


R = 0.4153
N = 12
Distance = 3.7 mi.

19MAR02:17:13:26

Site Pair: ASOS = BIL , PM = 301111065

Predicted vs Measured PM Fine
IMPROVE Model

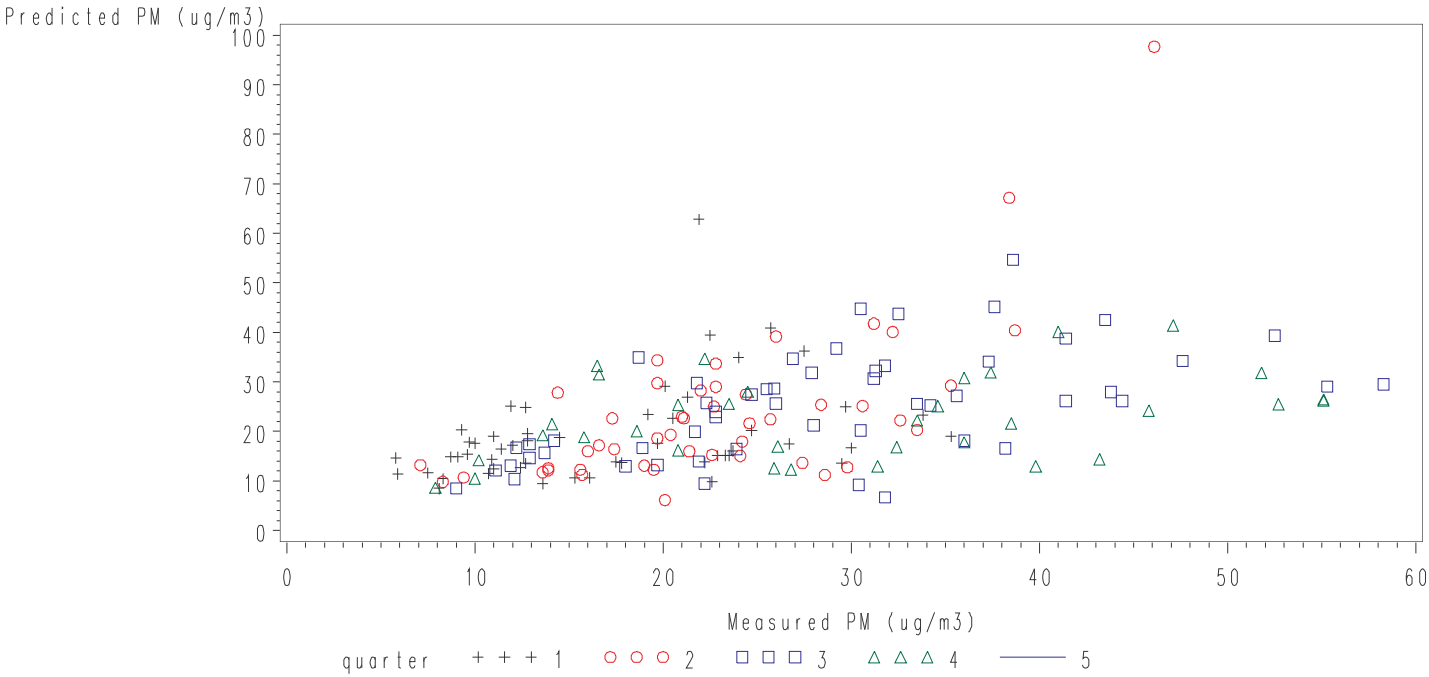


R = 0.3813
N = 75
Distance = 5.7 mi.

19MAR02:17:13:26

Site Pair: ASOS = BHM , PM = 010730023

Predicted vs Measured PM Fine
IMPROVE Model

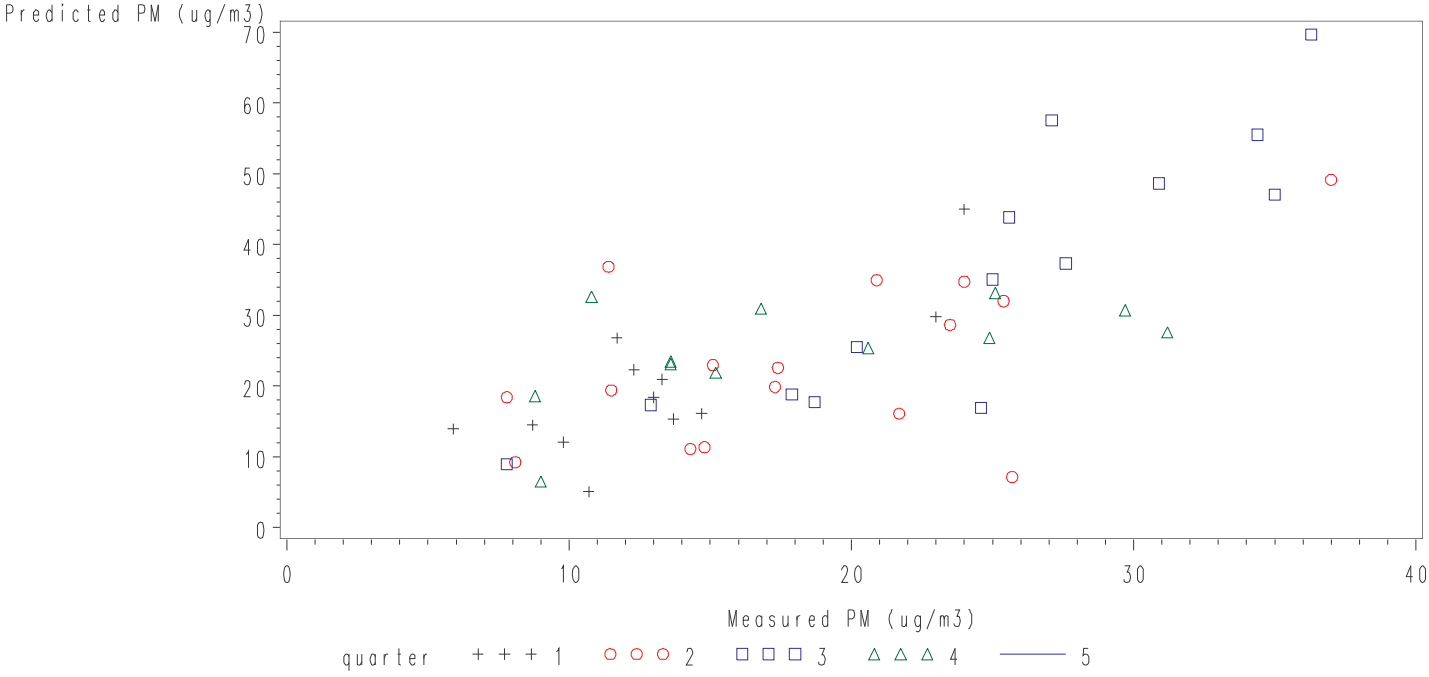


R = 0.5031
N = 187
Distance = 3.6 mi.

19MAR02:17:13:26

Site Pair: ASOS = ATL , PM = 131211001

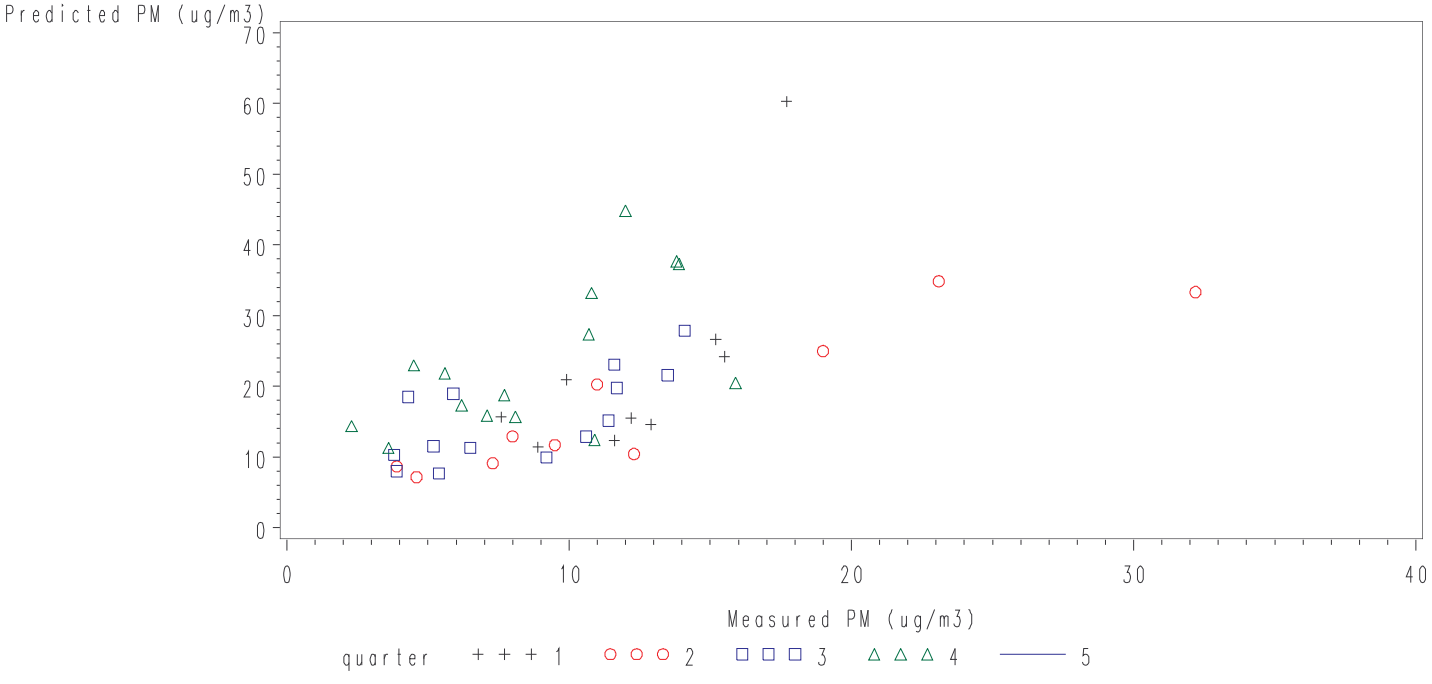
Predicted vs Measured PM Fine
IMPROVE Model



R = 0.7517
N = 54
Distance = 1.8 mi.

Site Pair: ASOS=ALO , PM=190130008

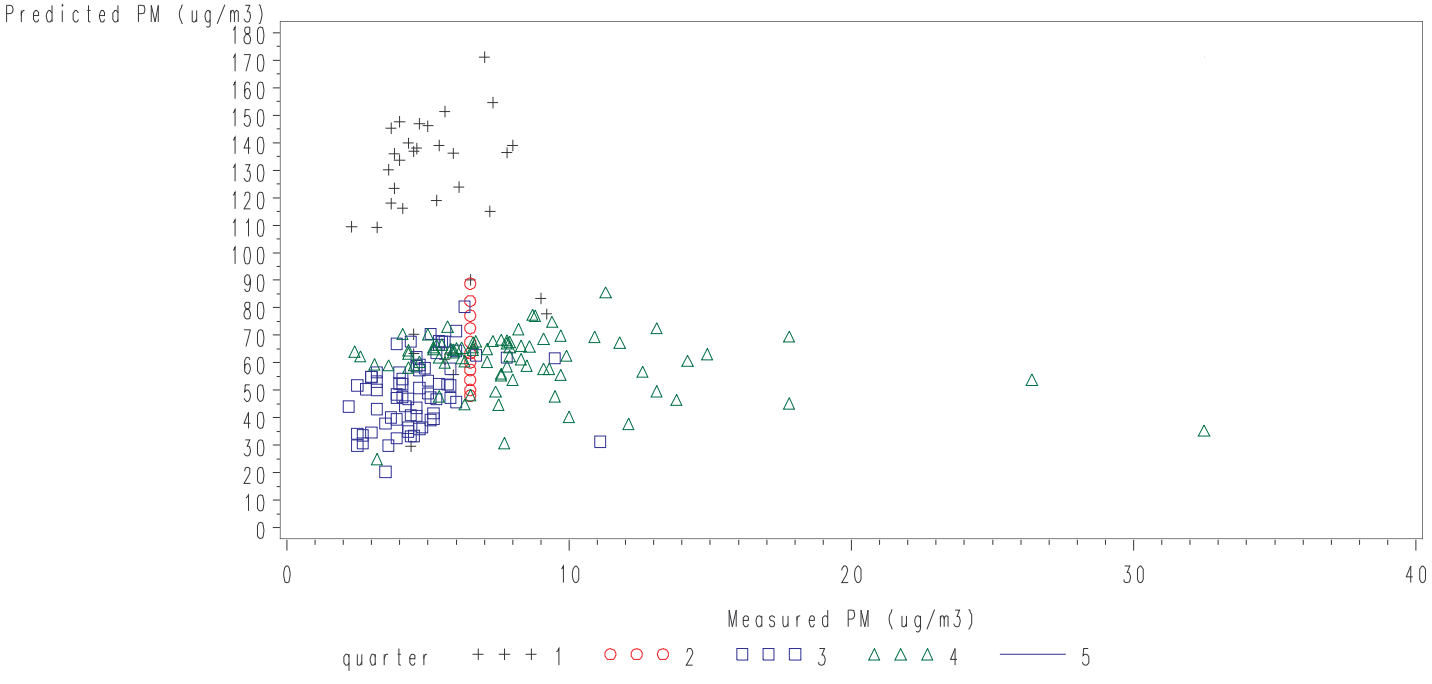
Predicted vs Measured PM Fine
IMPROVE Model



R = 0.6001
N = 48
Distance = 5.3 mi.

Site Pair: ASOS=ABQ , PM=350010024

Predicted vs Measured PM Fine
IMPROVE Model

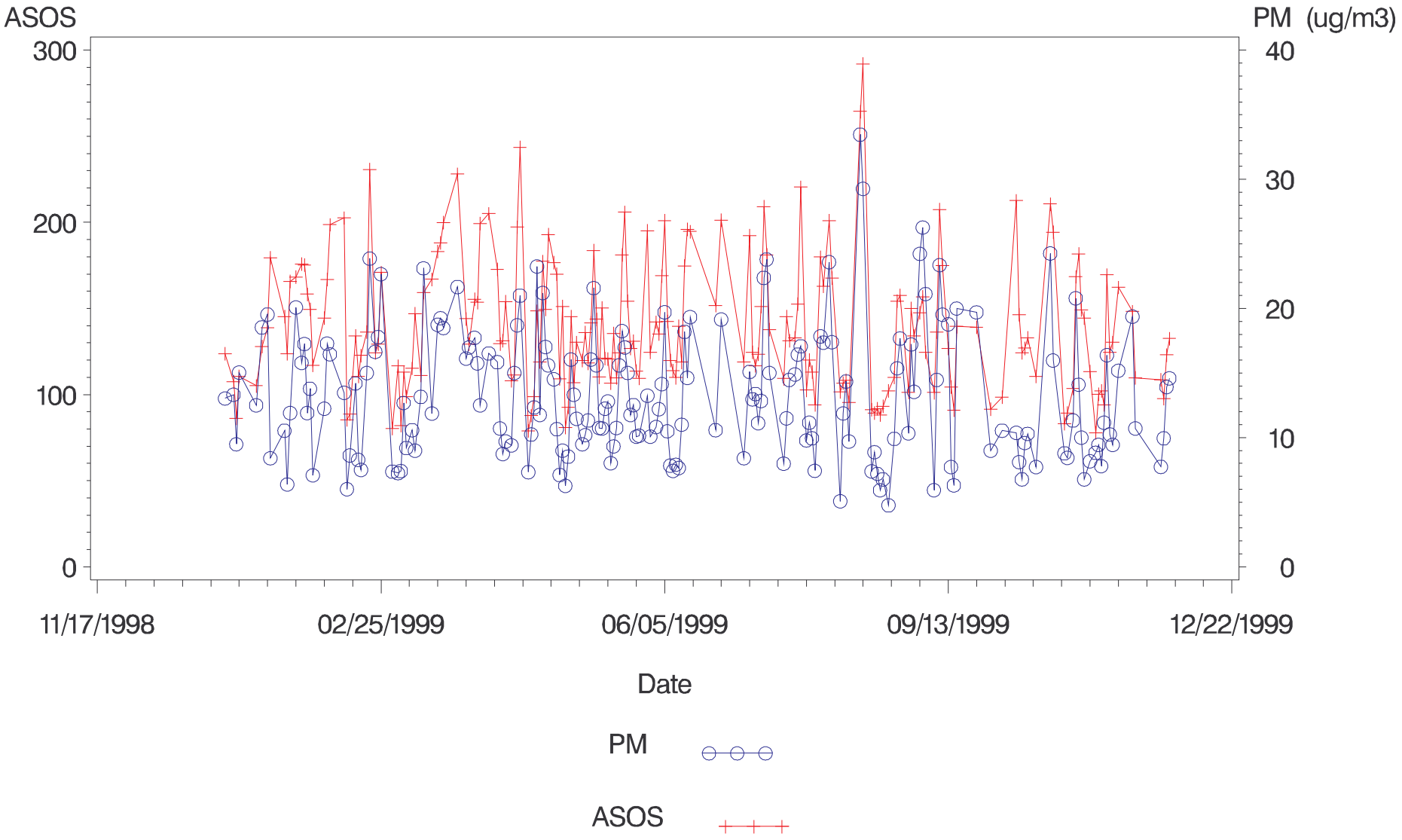


R = -.0527
N = 196
Distance = 2.3 mi.

Appendix E - Time series plots of ASOS 24-hour averaged light extinction coefficient and $PM_{2.5}$ concentrations from FRM sites

Site Pair: ASOS = TPA , PM = 120570030

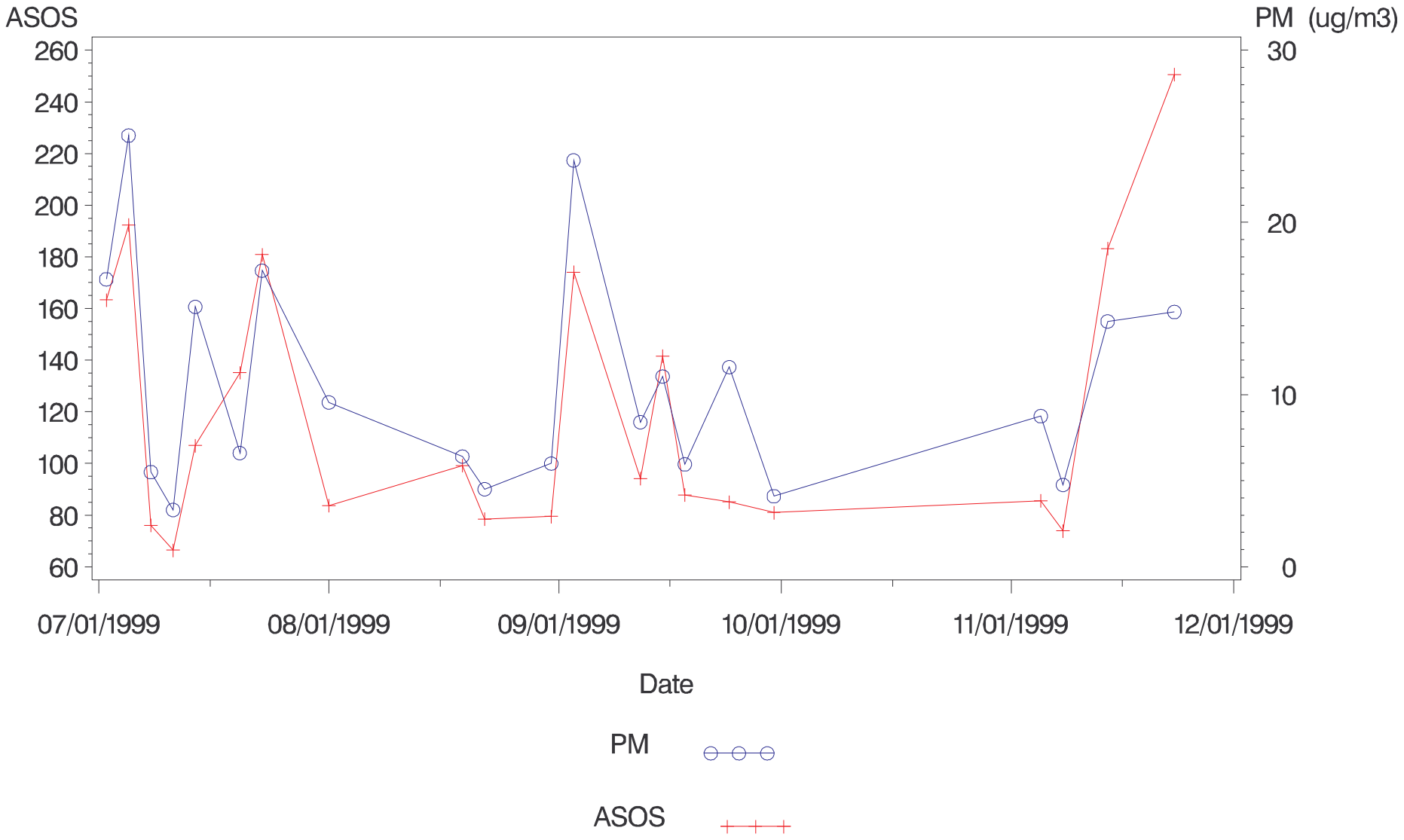
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = SYR , PM = 360671015

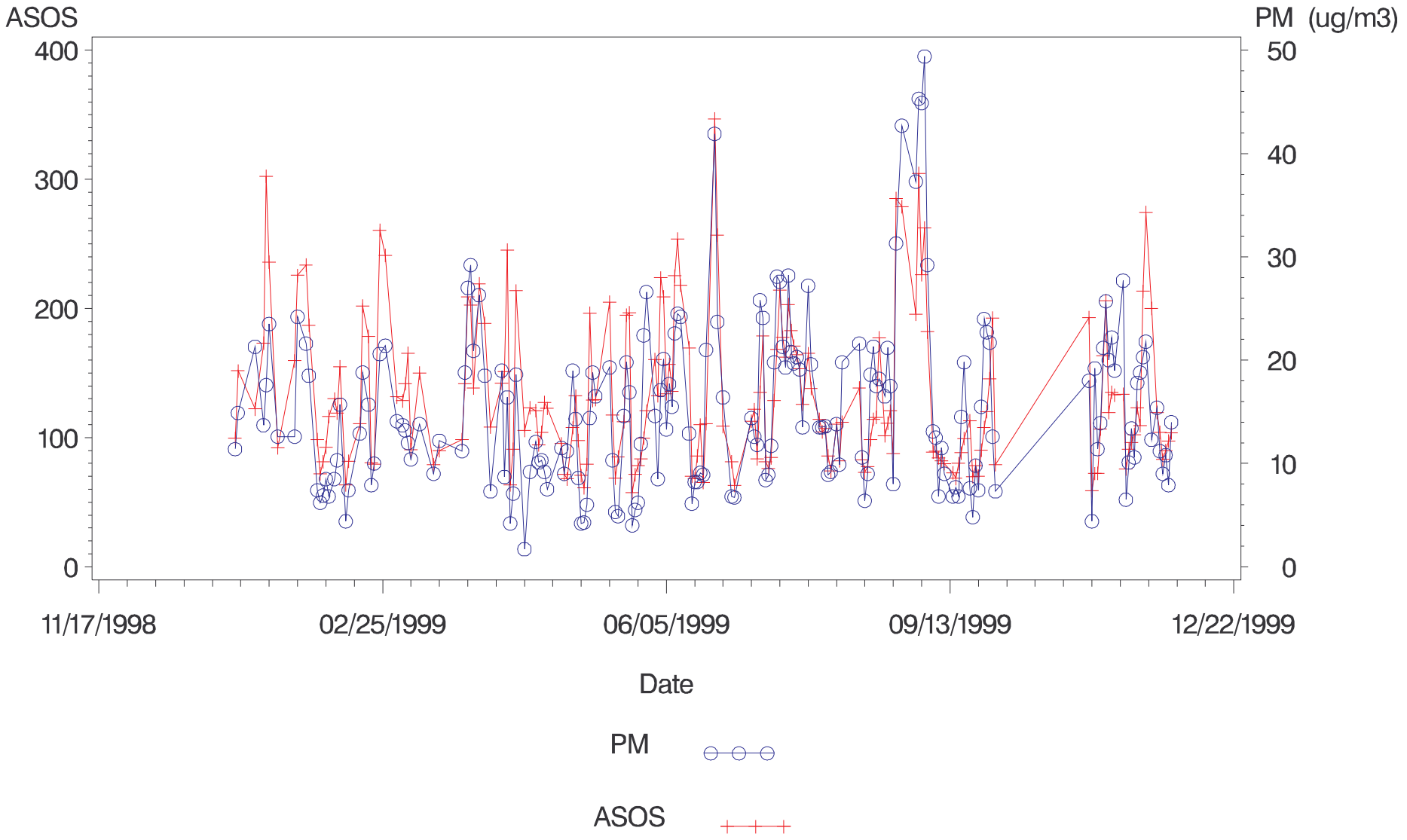
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = STL , PM = 295100086

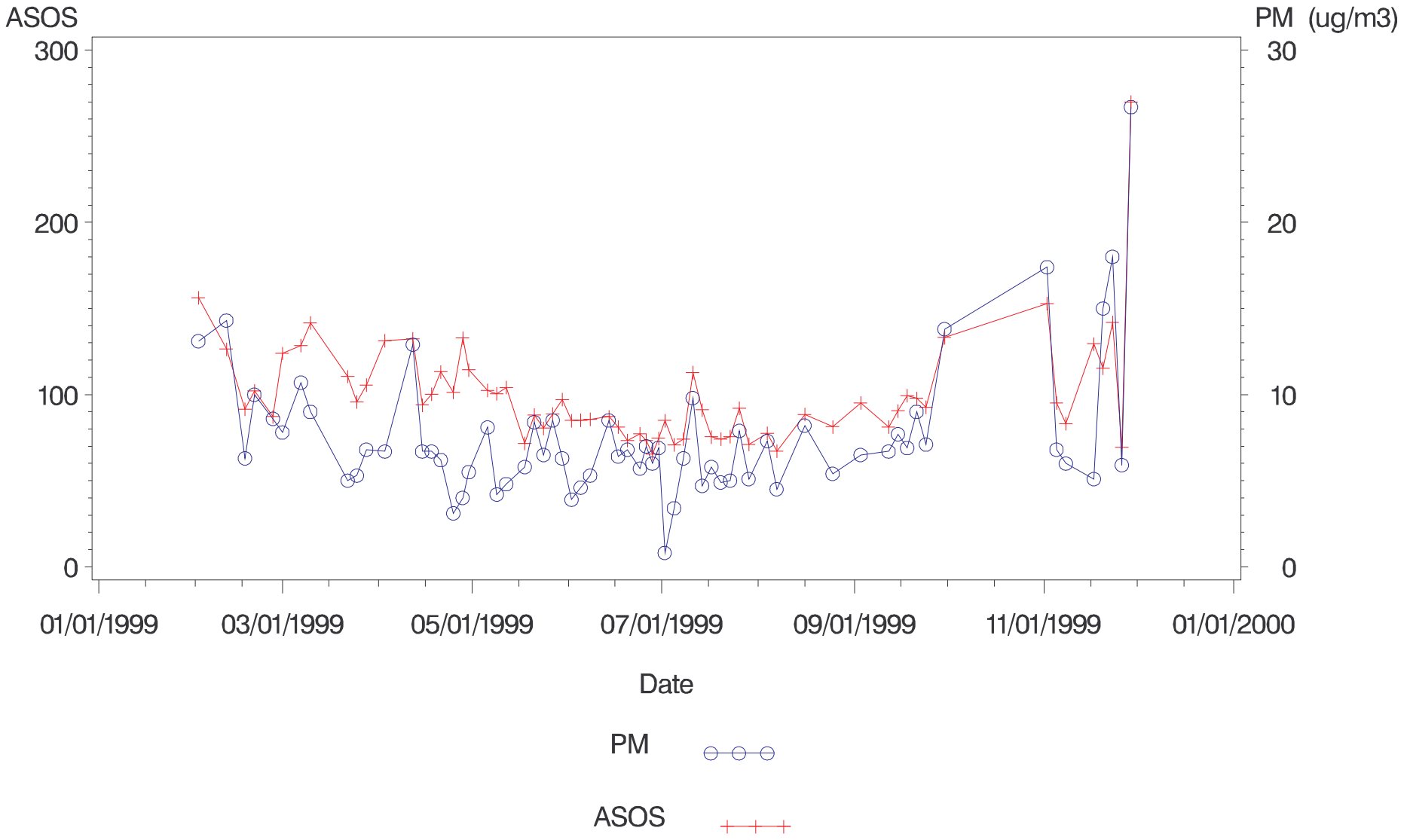
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = SLC , PM = 490353007

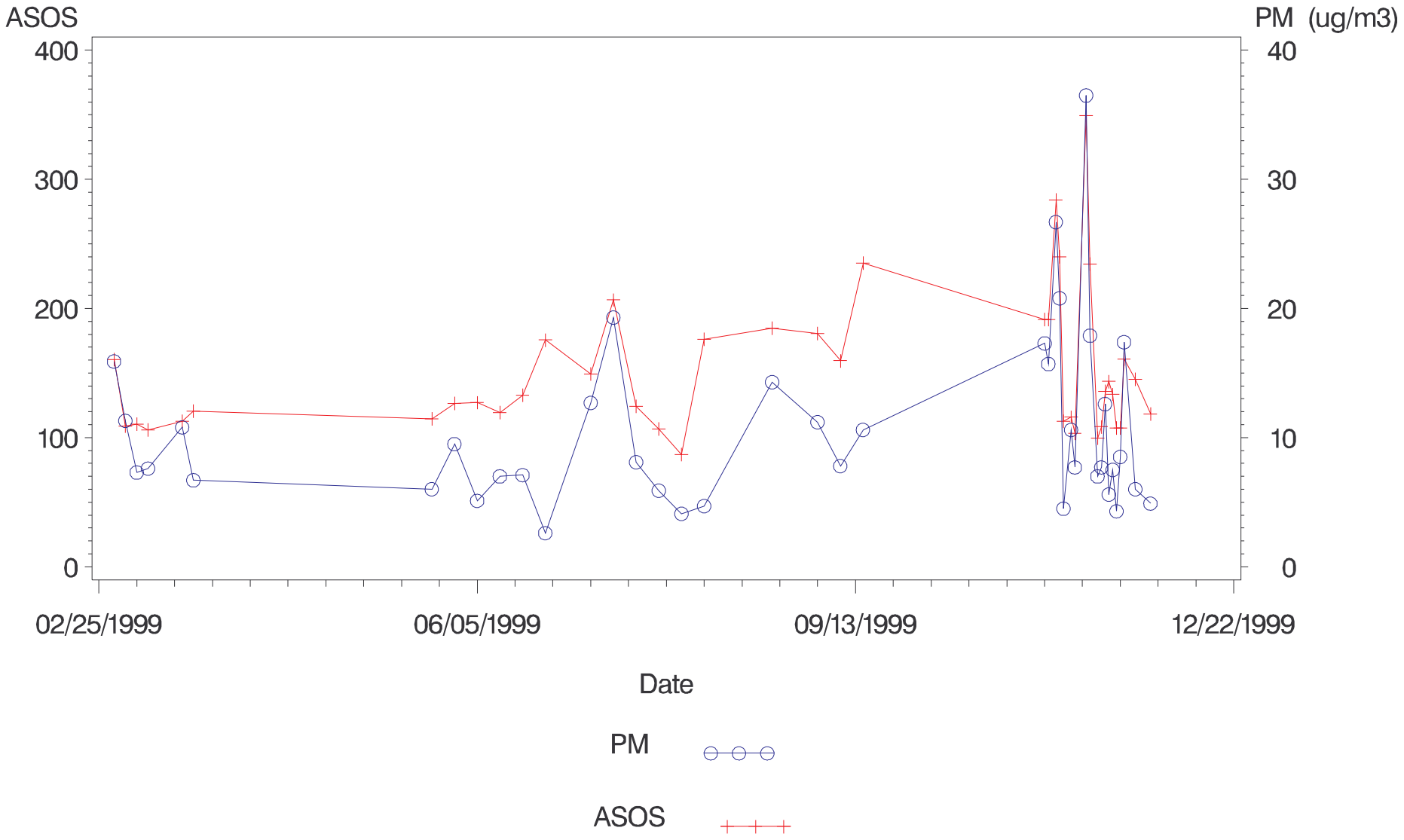
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = SFO , PM = 060750005

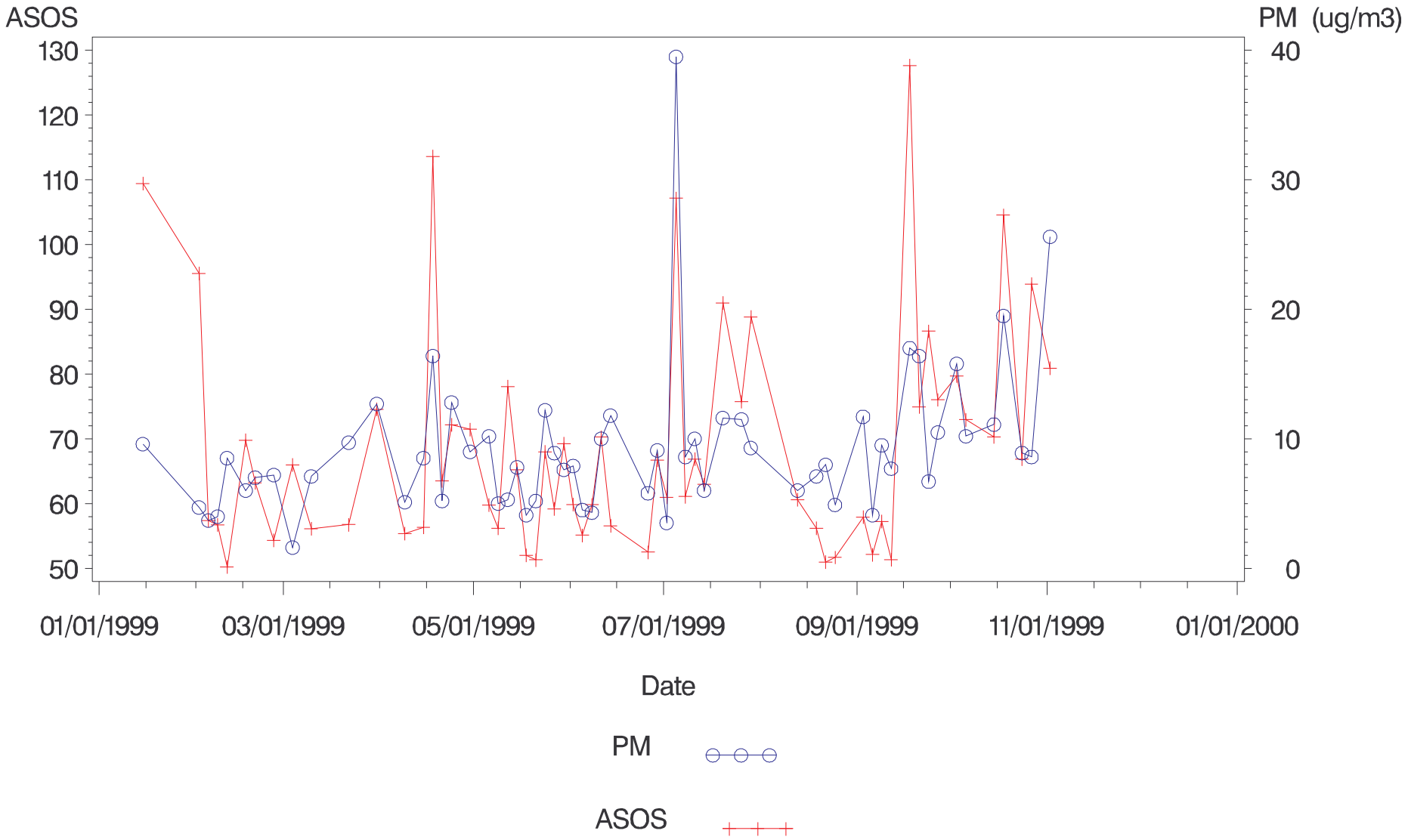
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = SEA , PM = 530332004

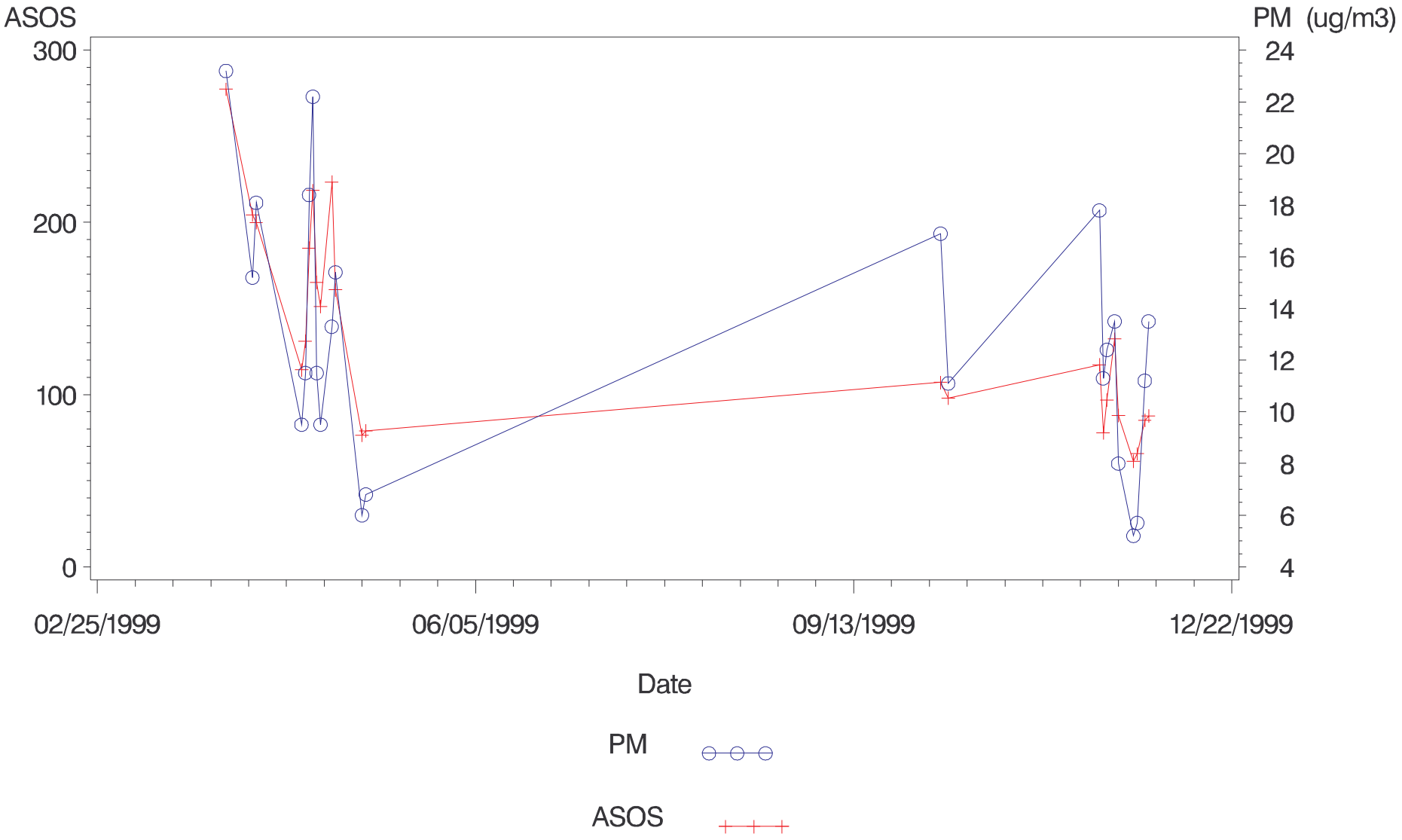
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = SAT , PM = 480290052

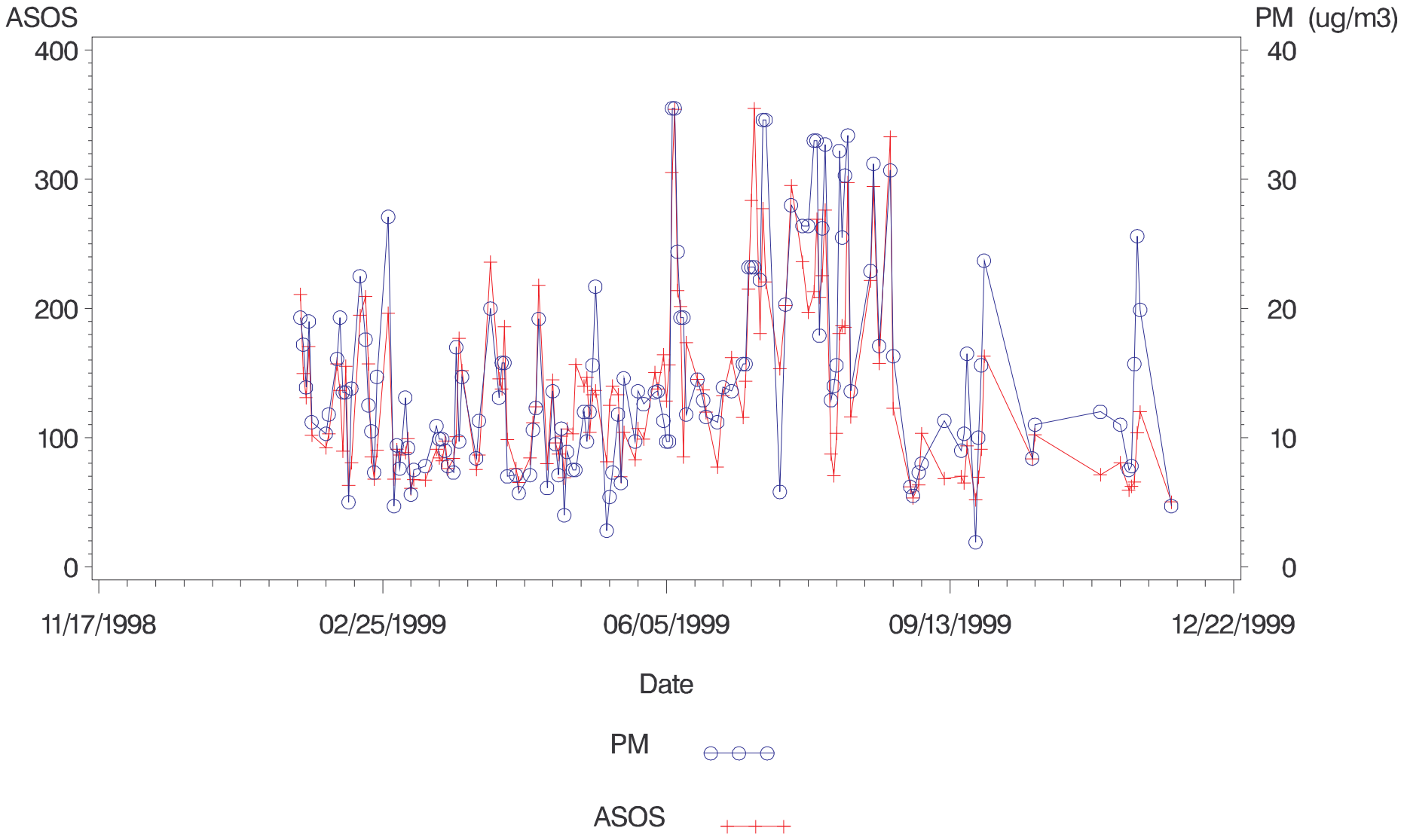
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = RIC , PM = 517600020

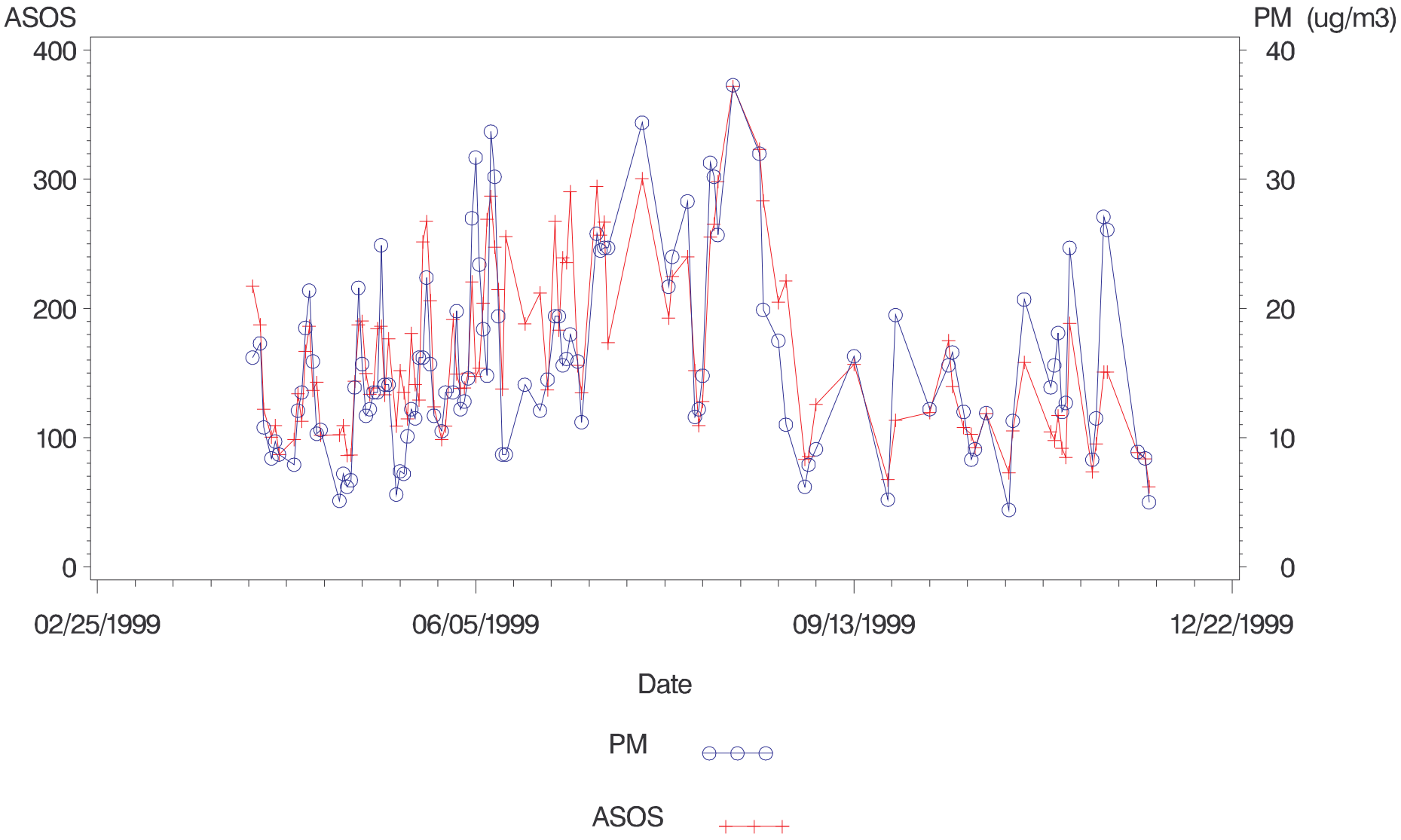
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = RDU , PM = 370630001

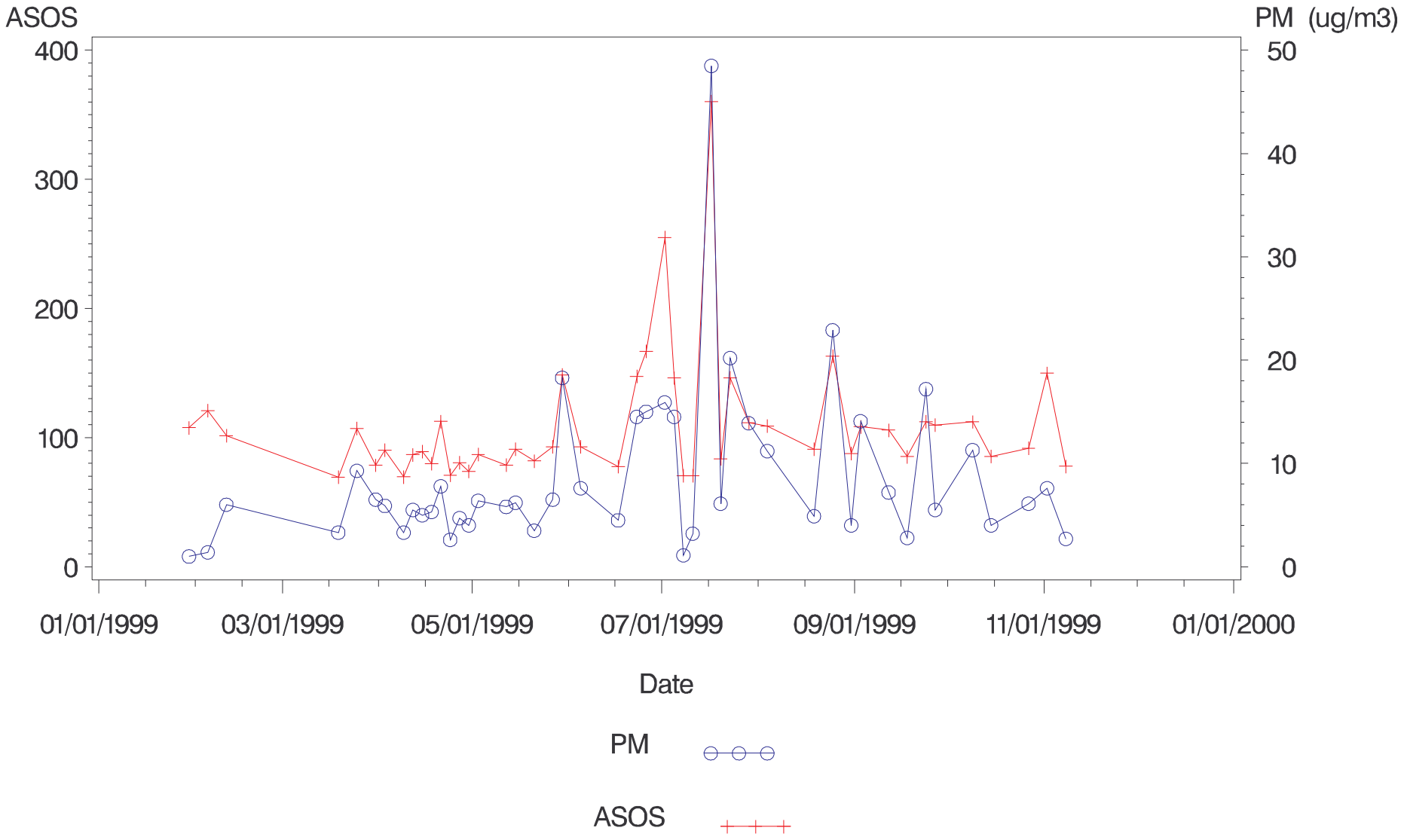
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = PWM , PM = 230052003

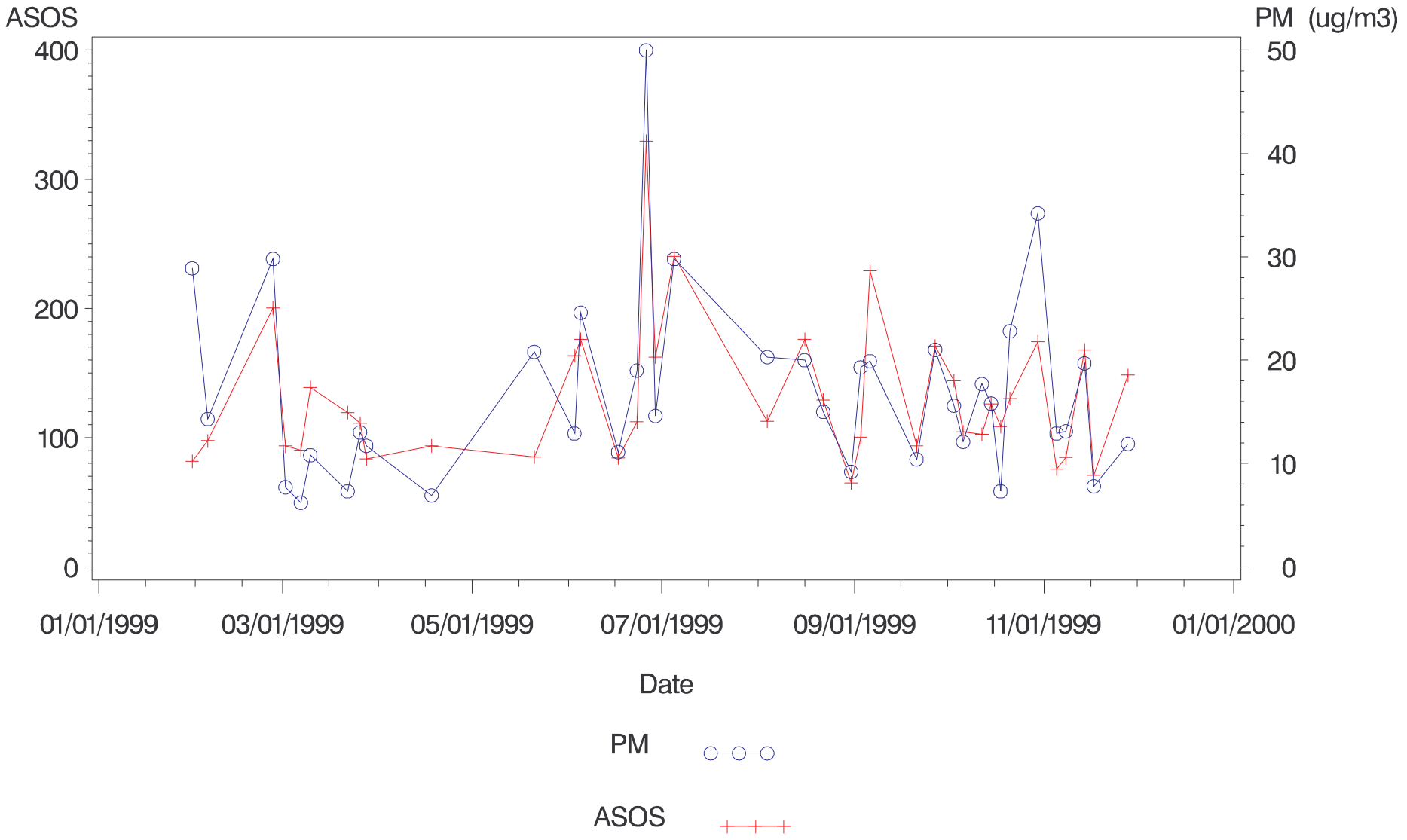
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = PIT , PM = 420030116

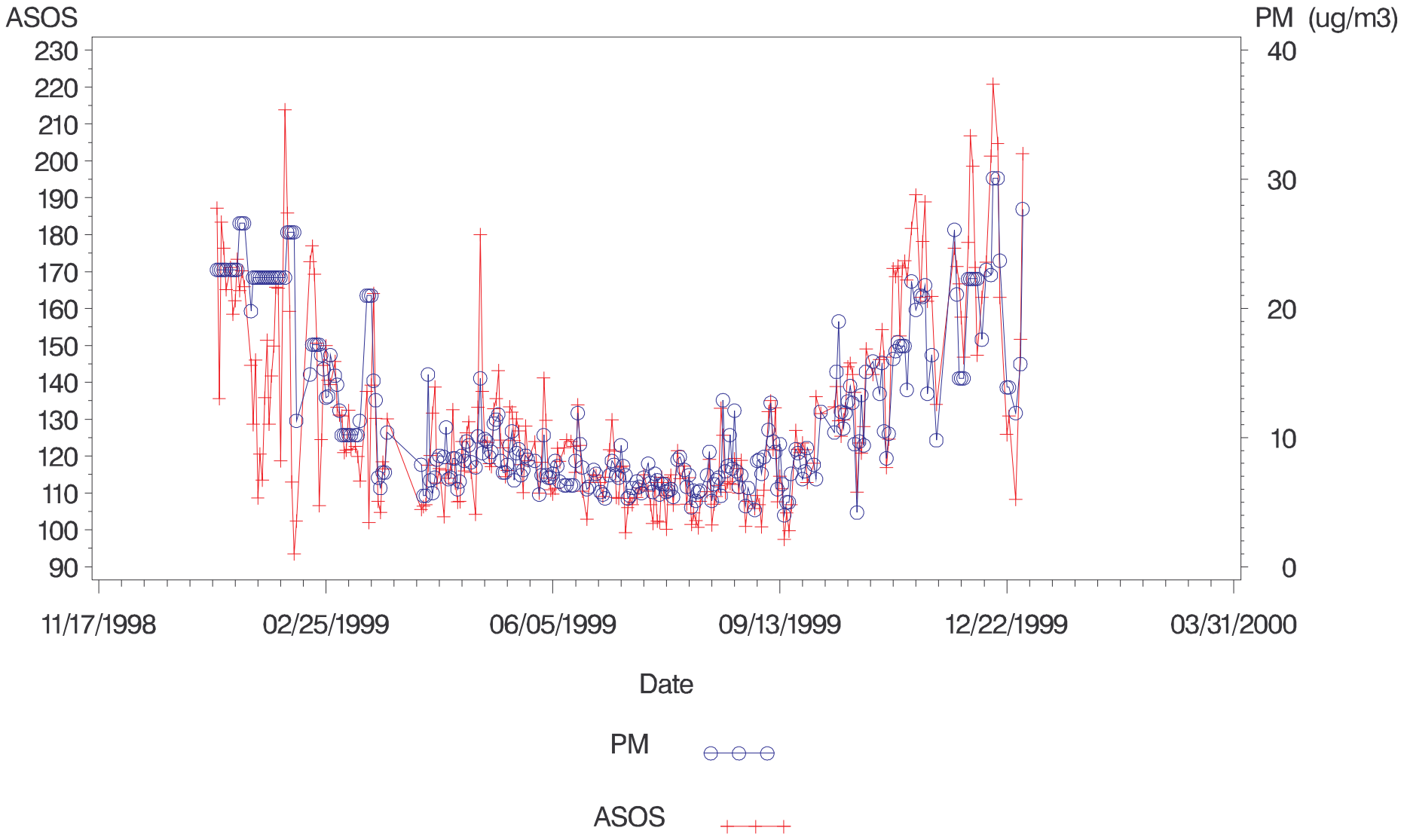
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = PHX , PM = 040139997

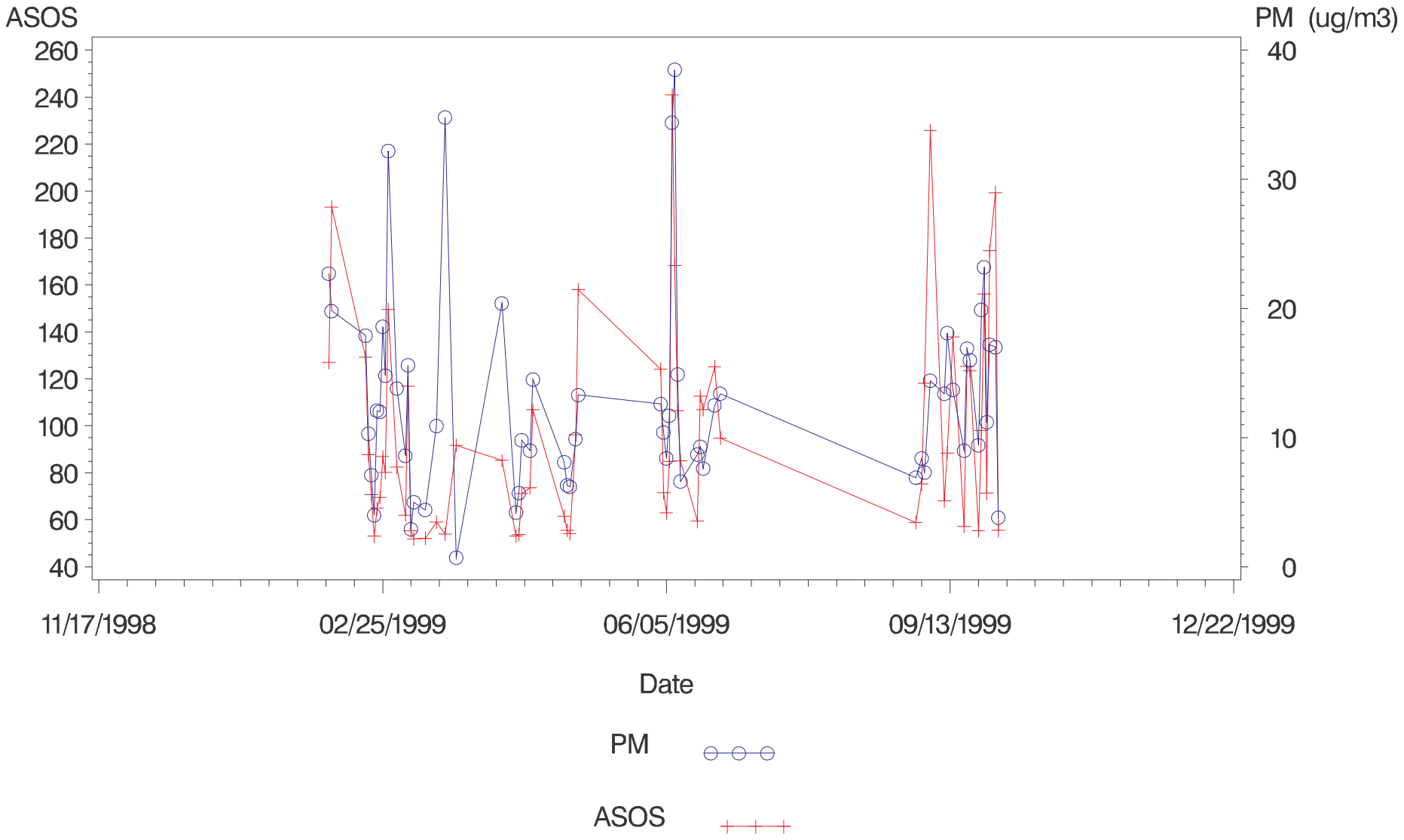
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = PHL , PM = 421010136

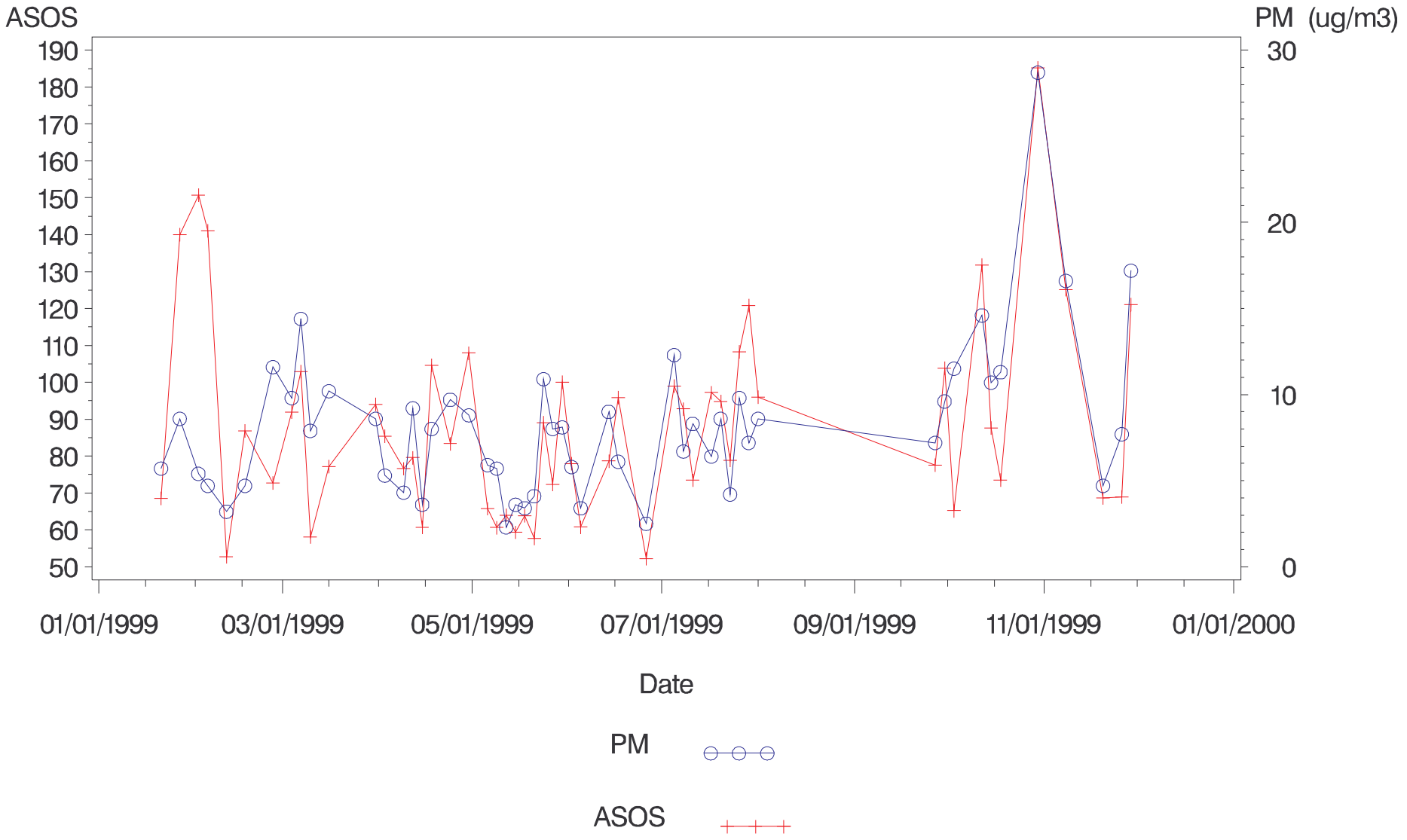
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = PDX , PM = 530110013

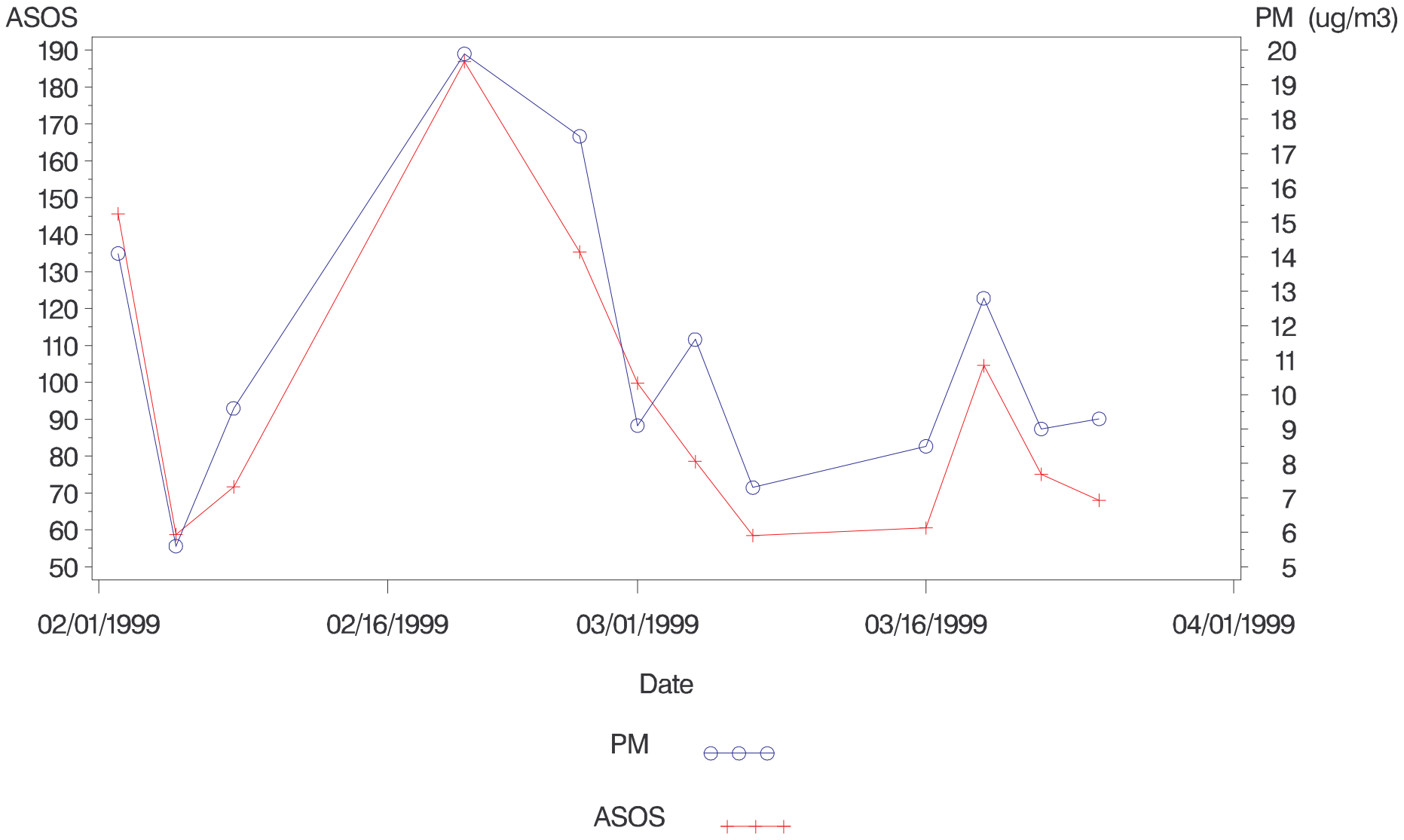
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = PAH , PM = 211451004

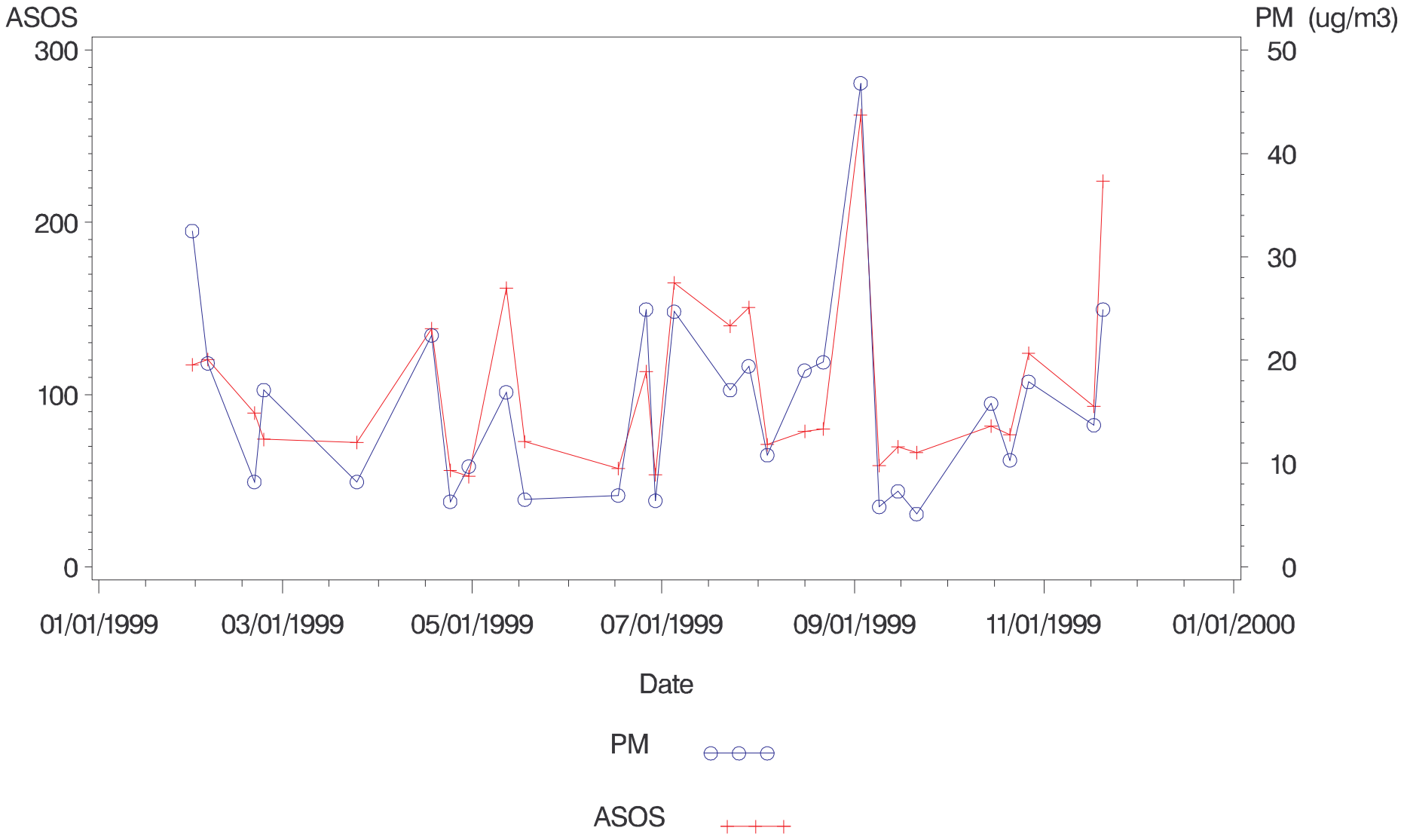
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = ORD , PM = 170314006

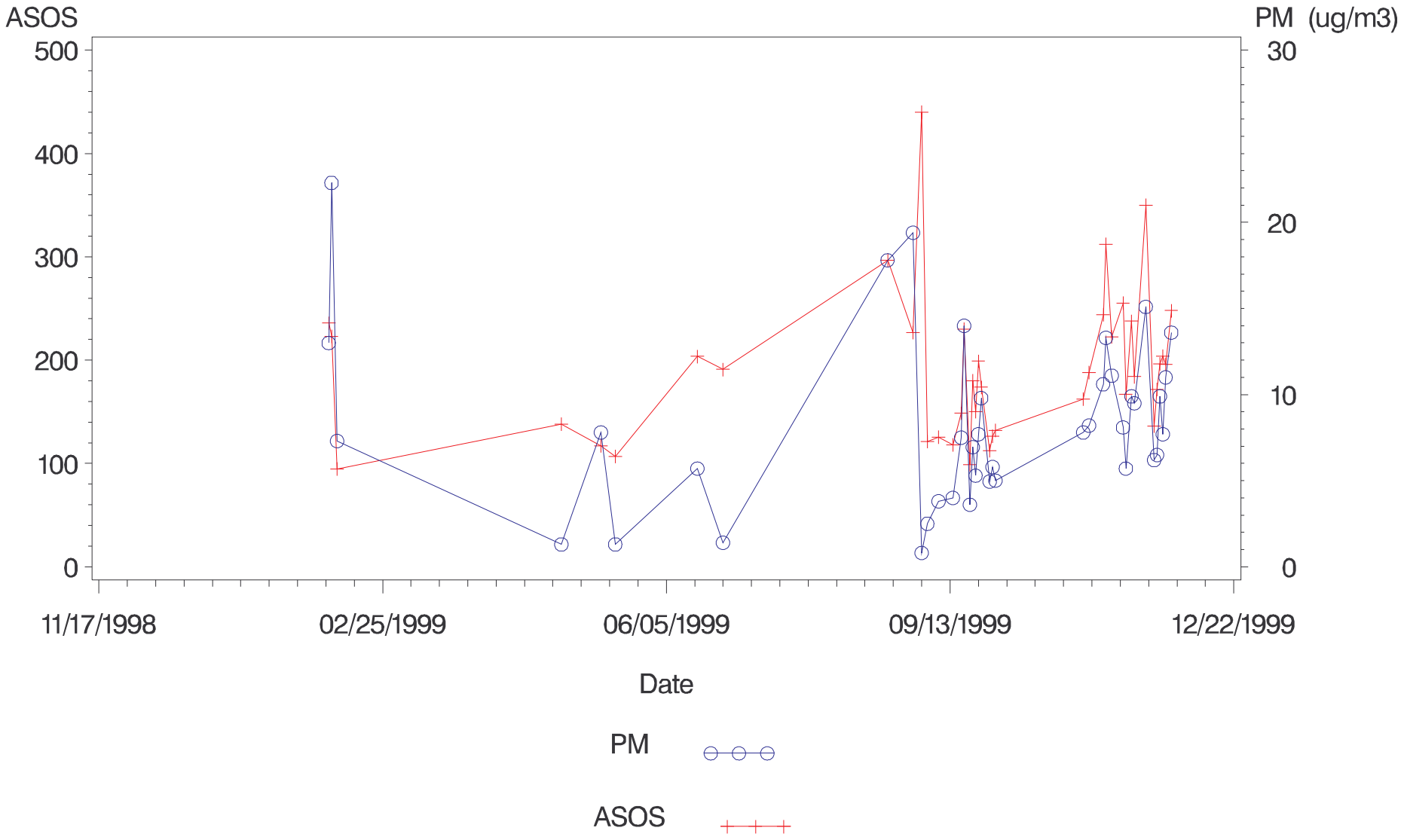
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = OMA , PM = 310550019

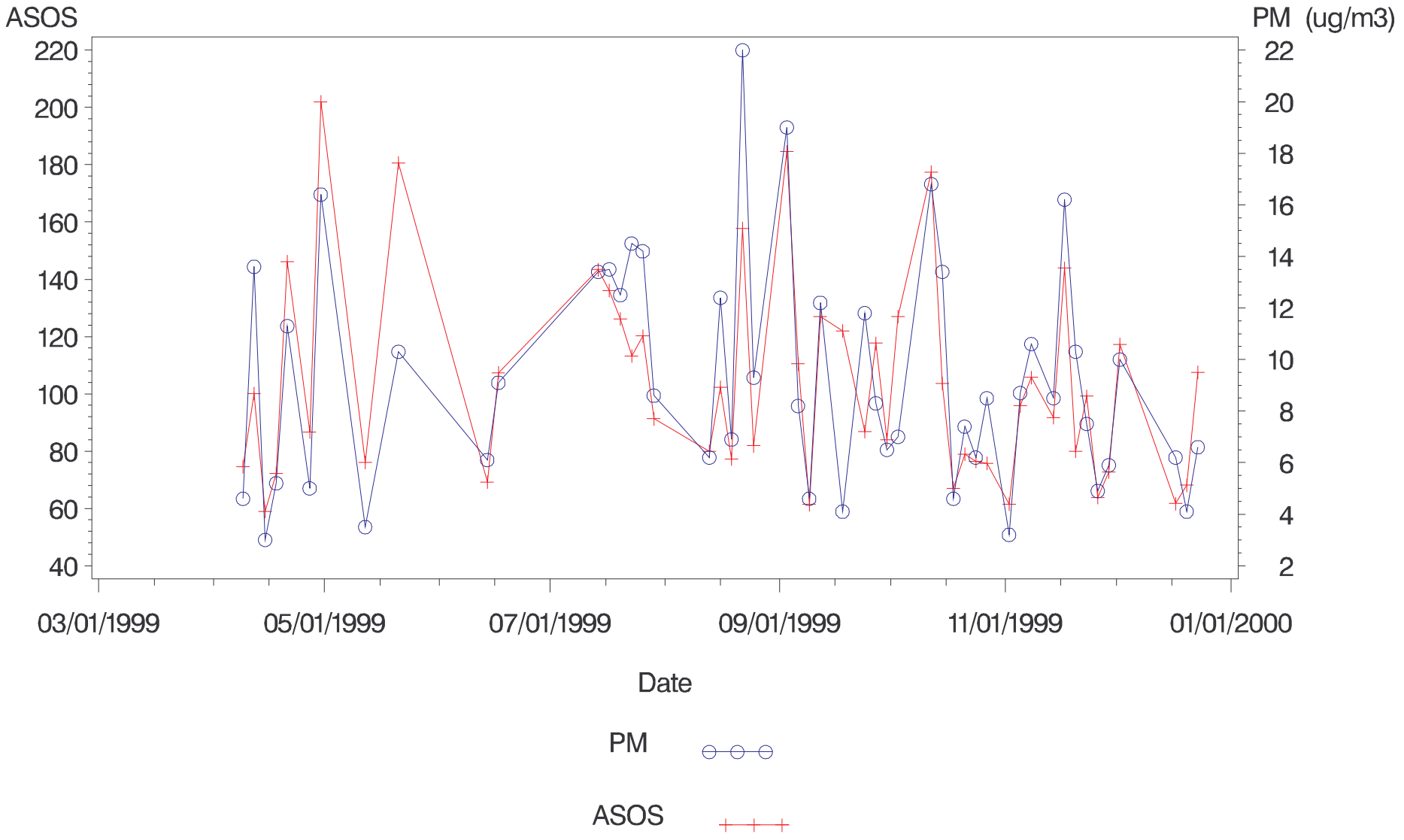
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = OKC , PM = 401090038

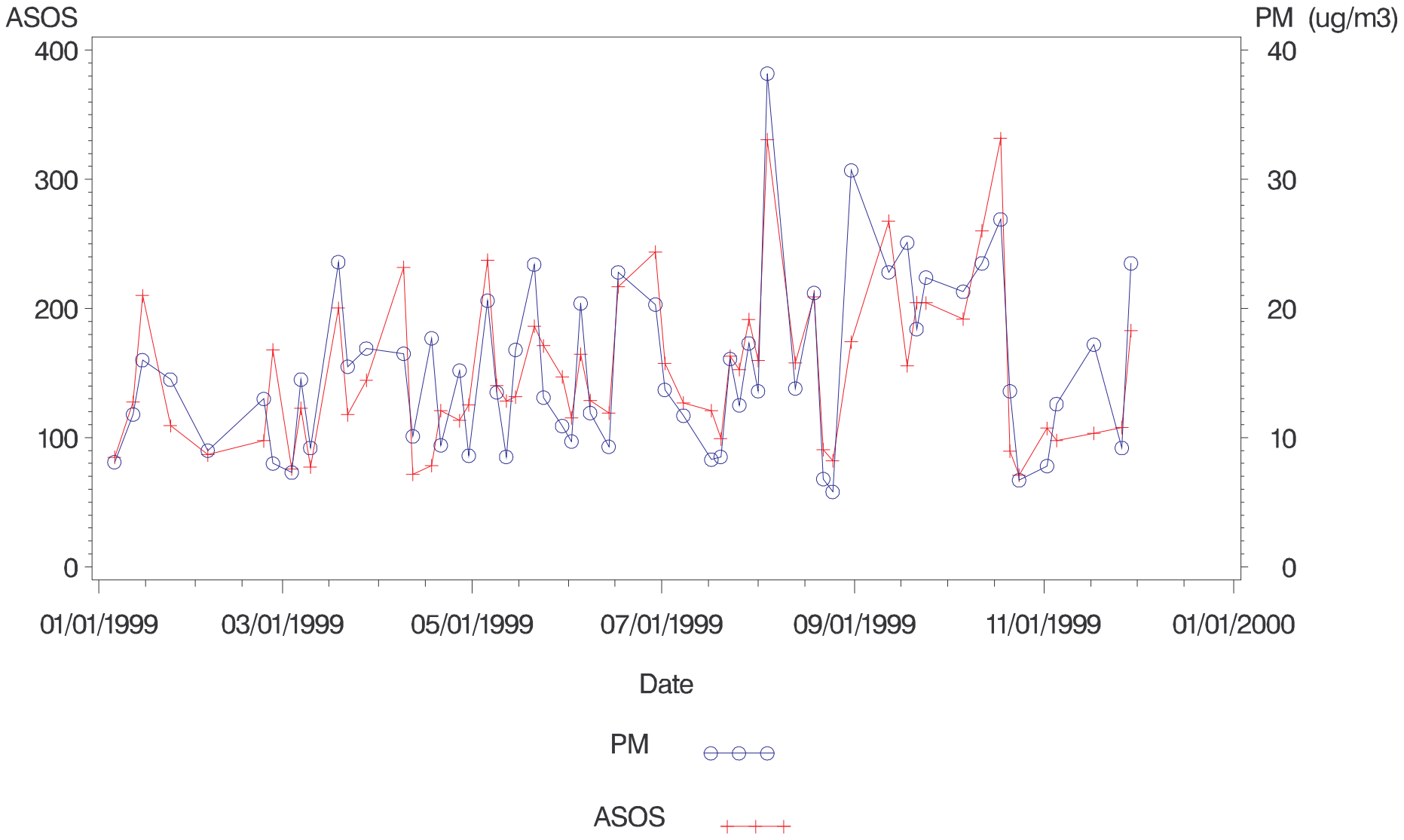
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = MSY , PM = 220710012

ASOS and PM Fine Over Time



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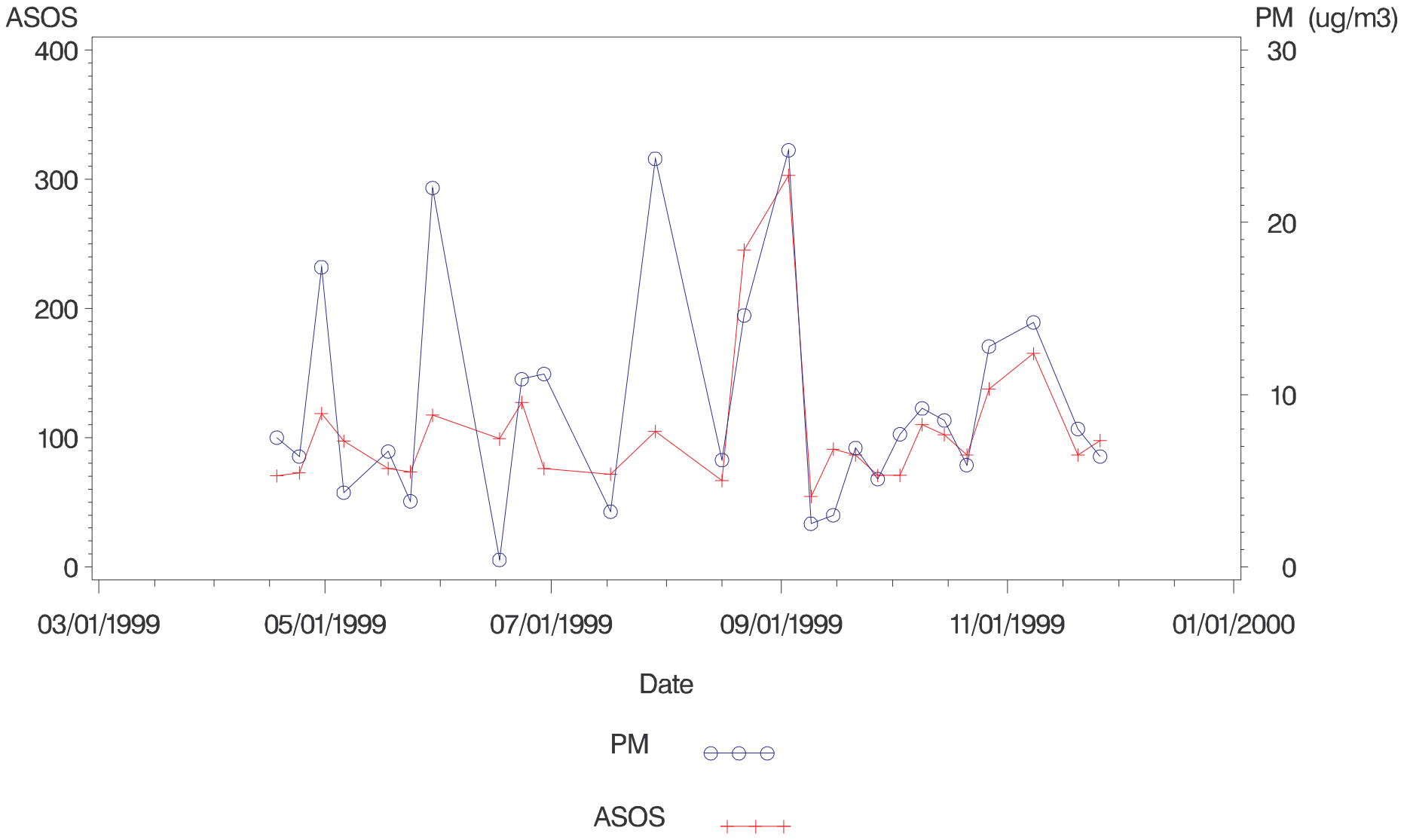
Site Pair: ASOS = MSP , PM = 271230872

ASOS and PM Fine Over Time



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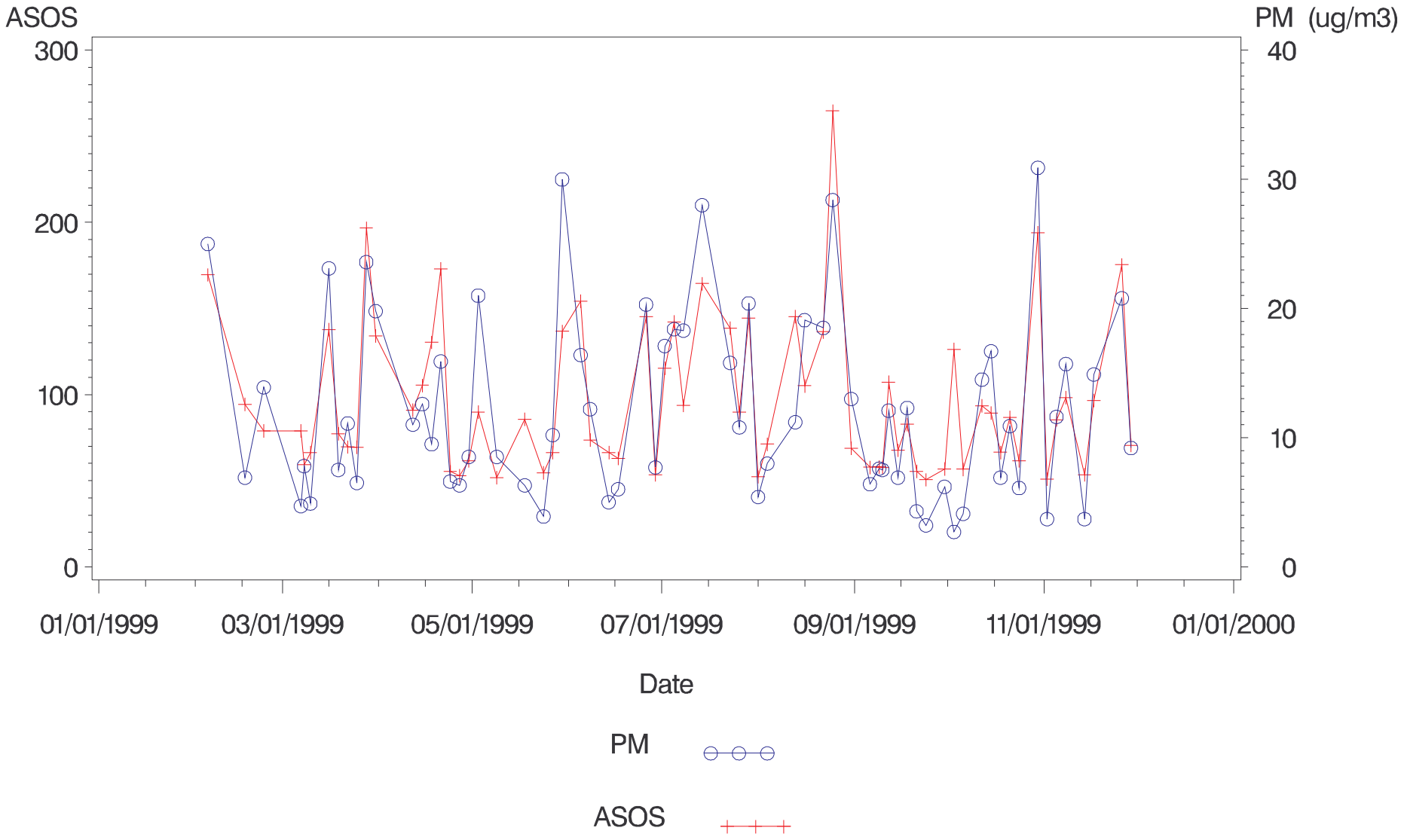
Site Pair: ASOS = MKE , PM = 550790099

ASOS and PM Fine Over Time



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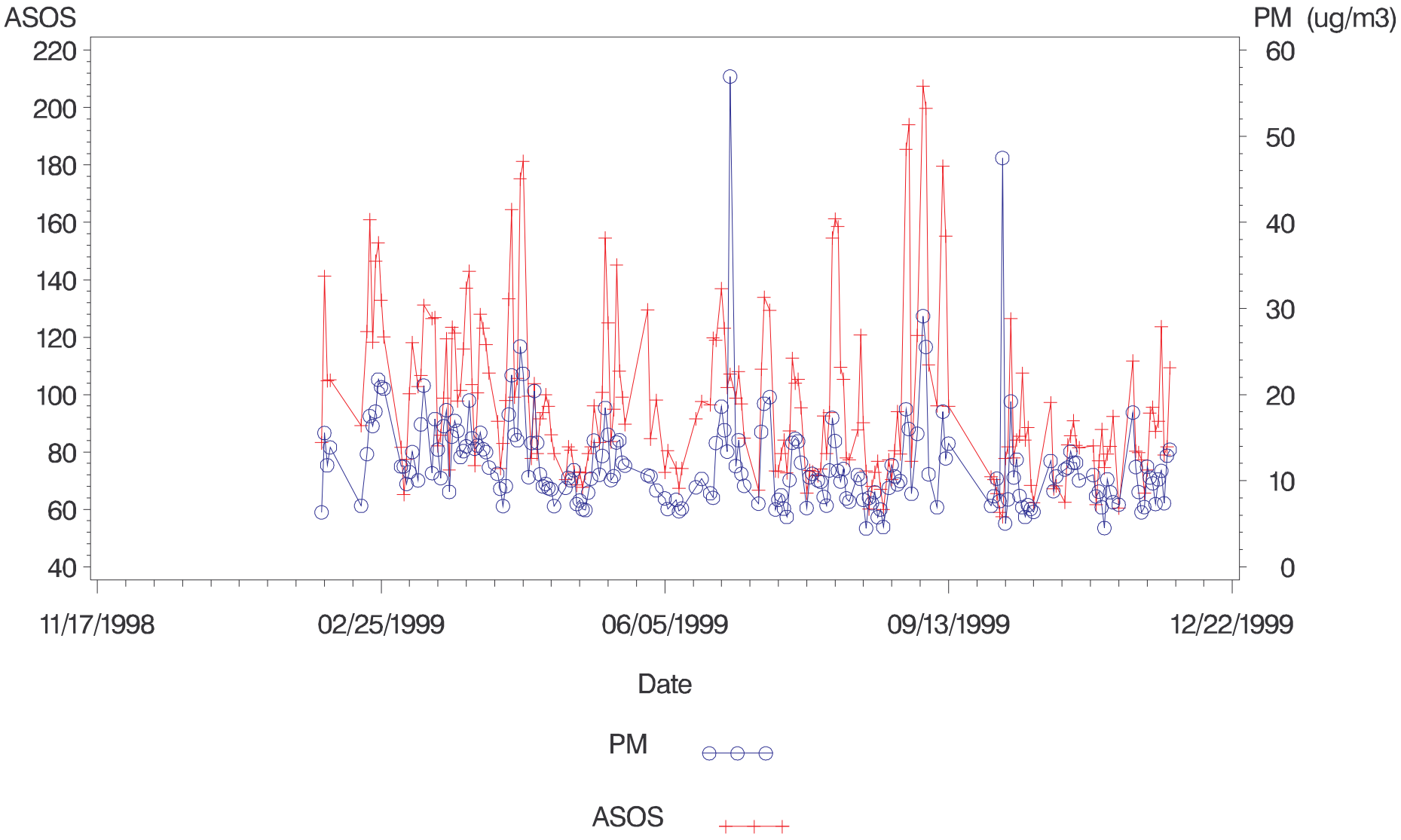
Site Pair: ASOS = MIA , PM = 120251016

ASOS and PM Fine Over Time



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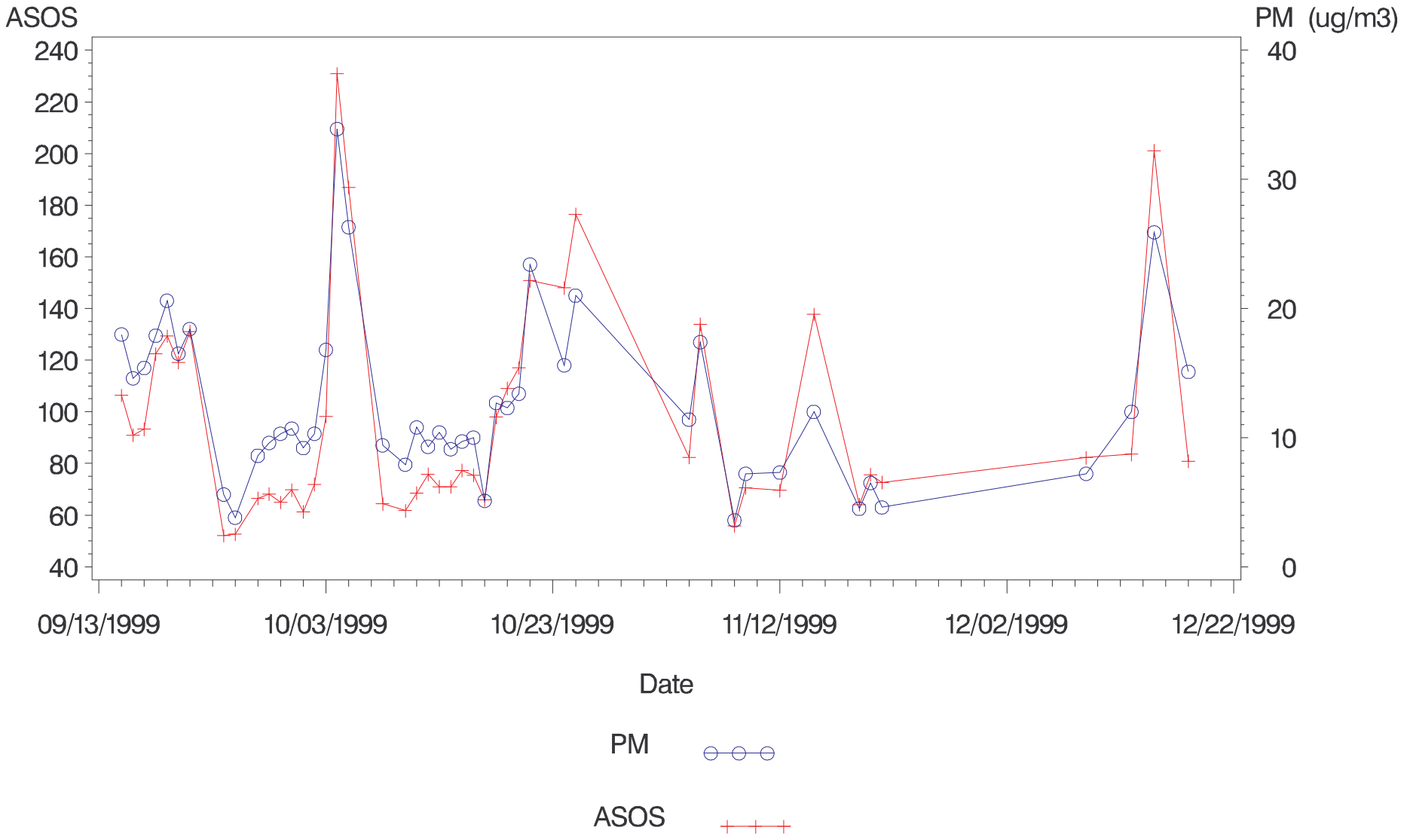
Site Pair: ASOS = MFR , PM = 410292129

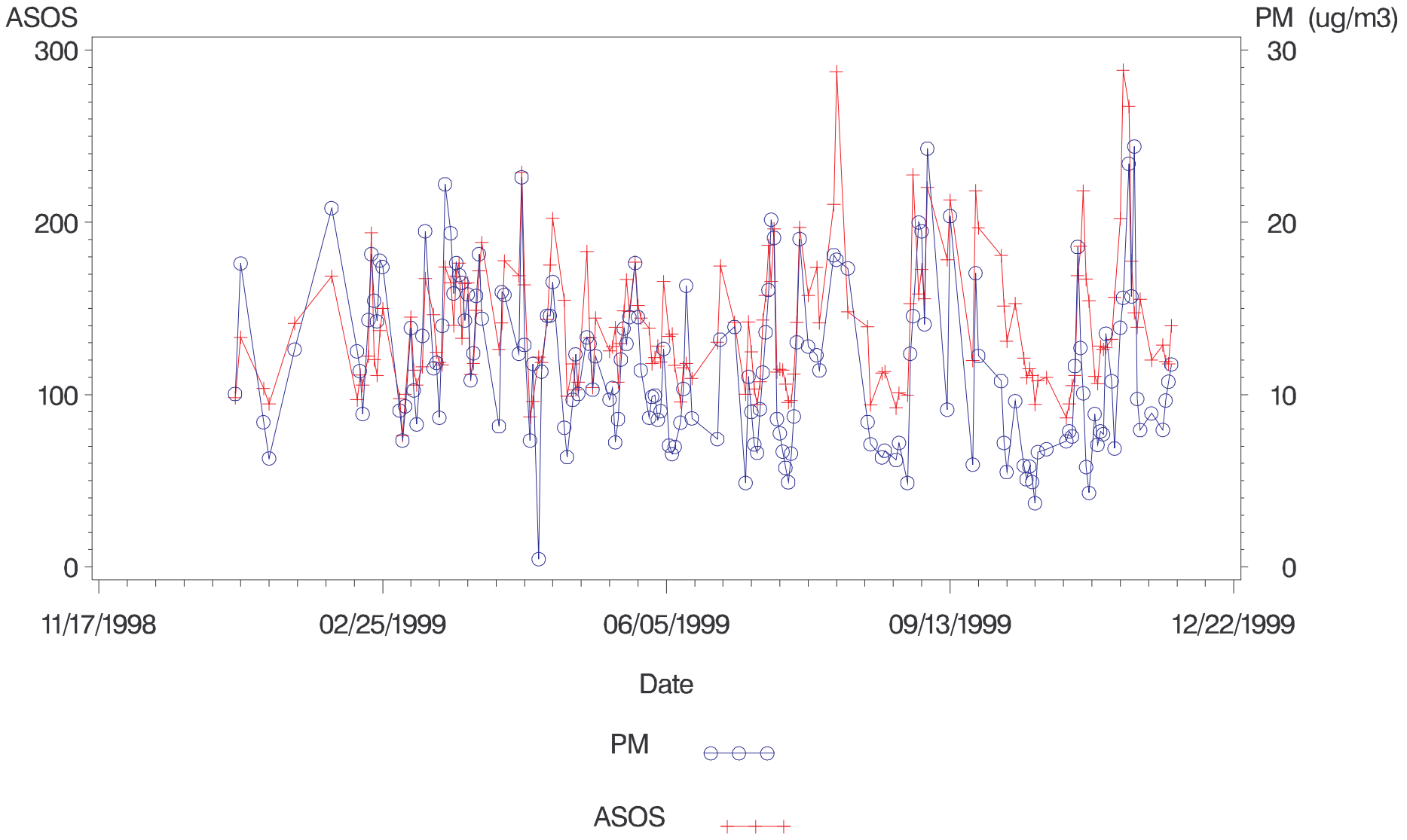
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = MCO , PM = 120951004

ASOS and PM Fine Over Time



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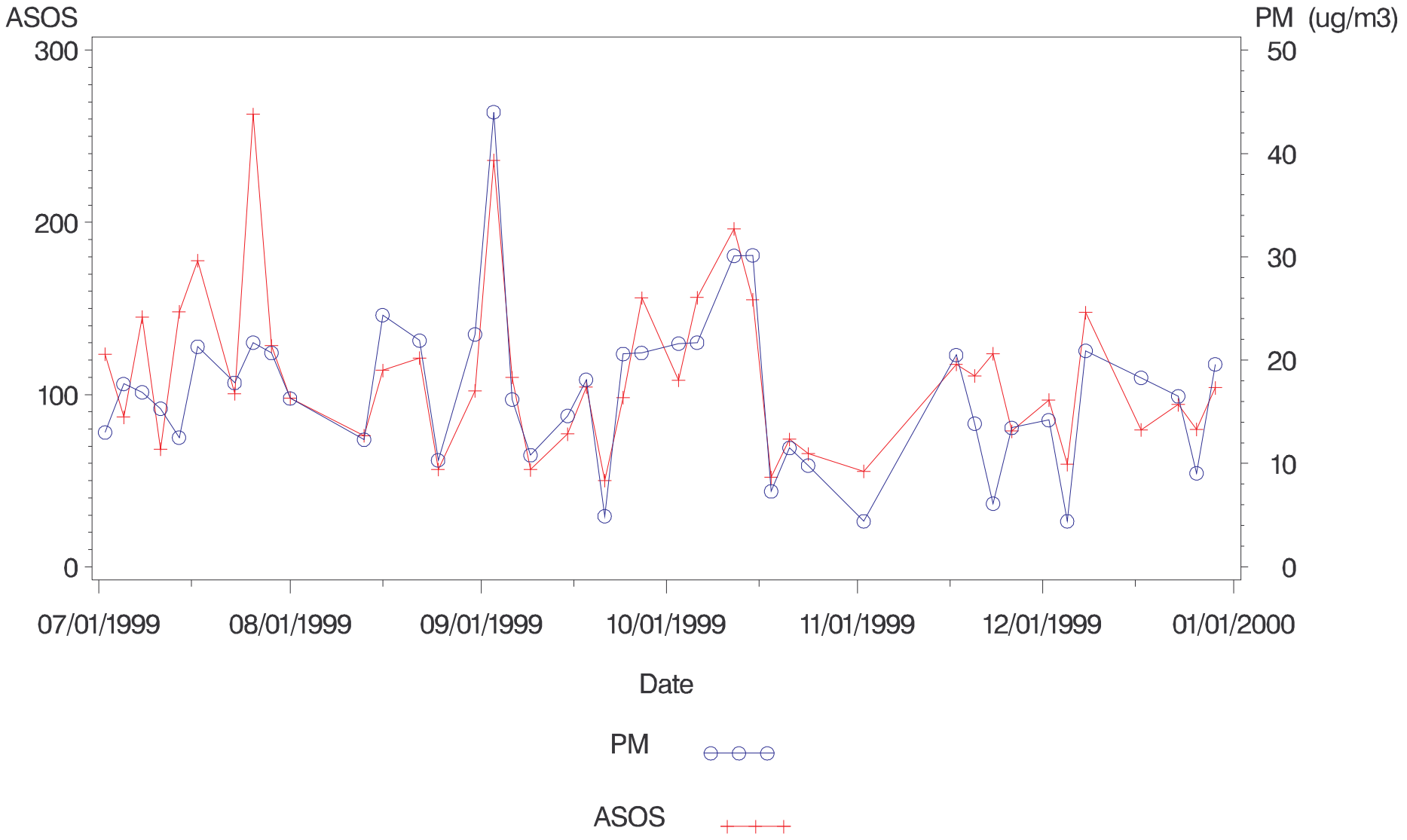
Site Pair: ASOS = LIT , PM = 051191008

ASOS and PM Fine Over Time



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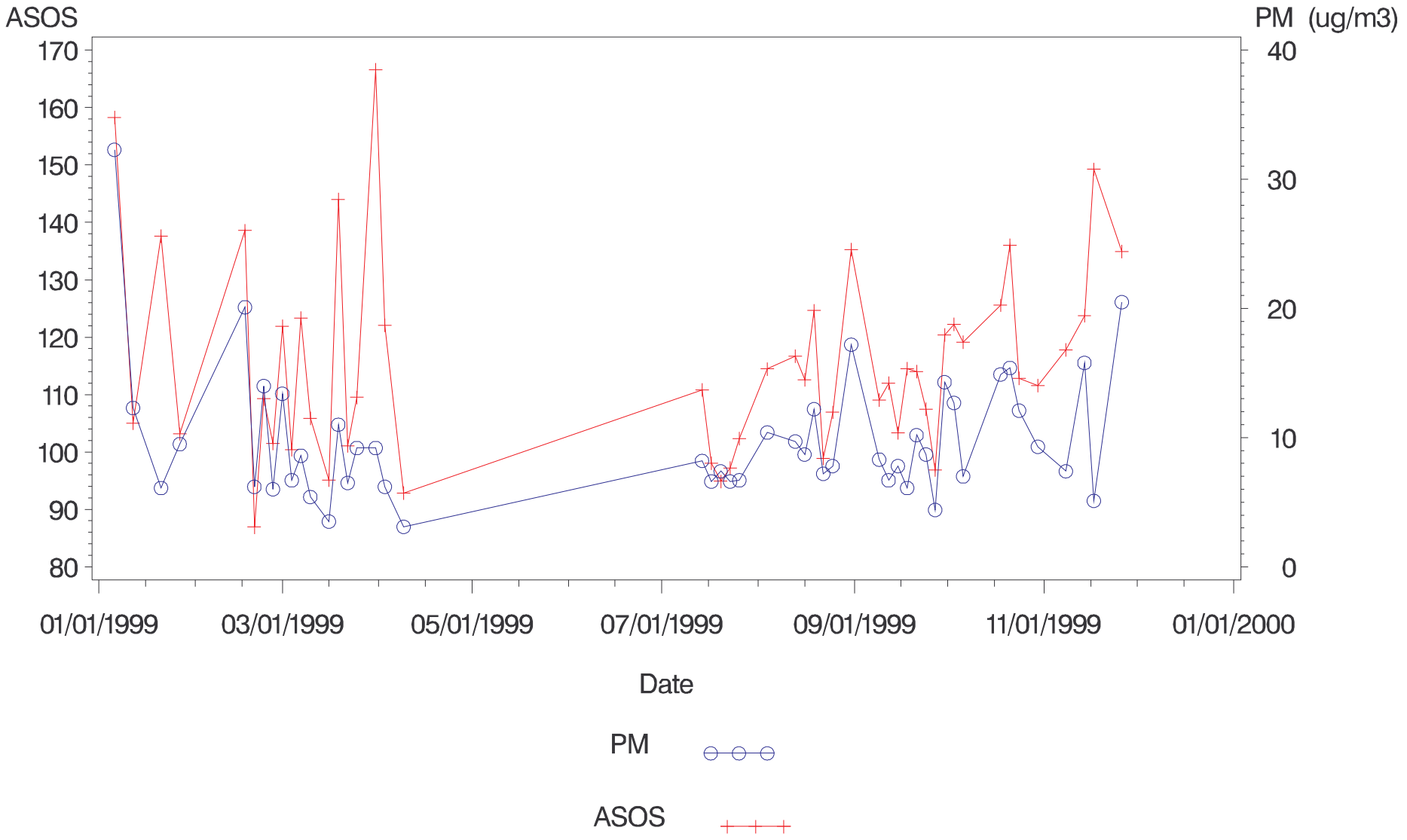
Site Pair: ASOS = LAS , PM = 320032002

ASOS and PM Fine Over Time



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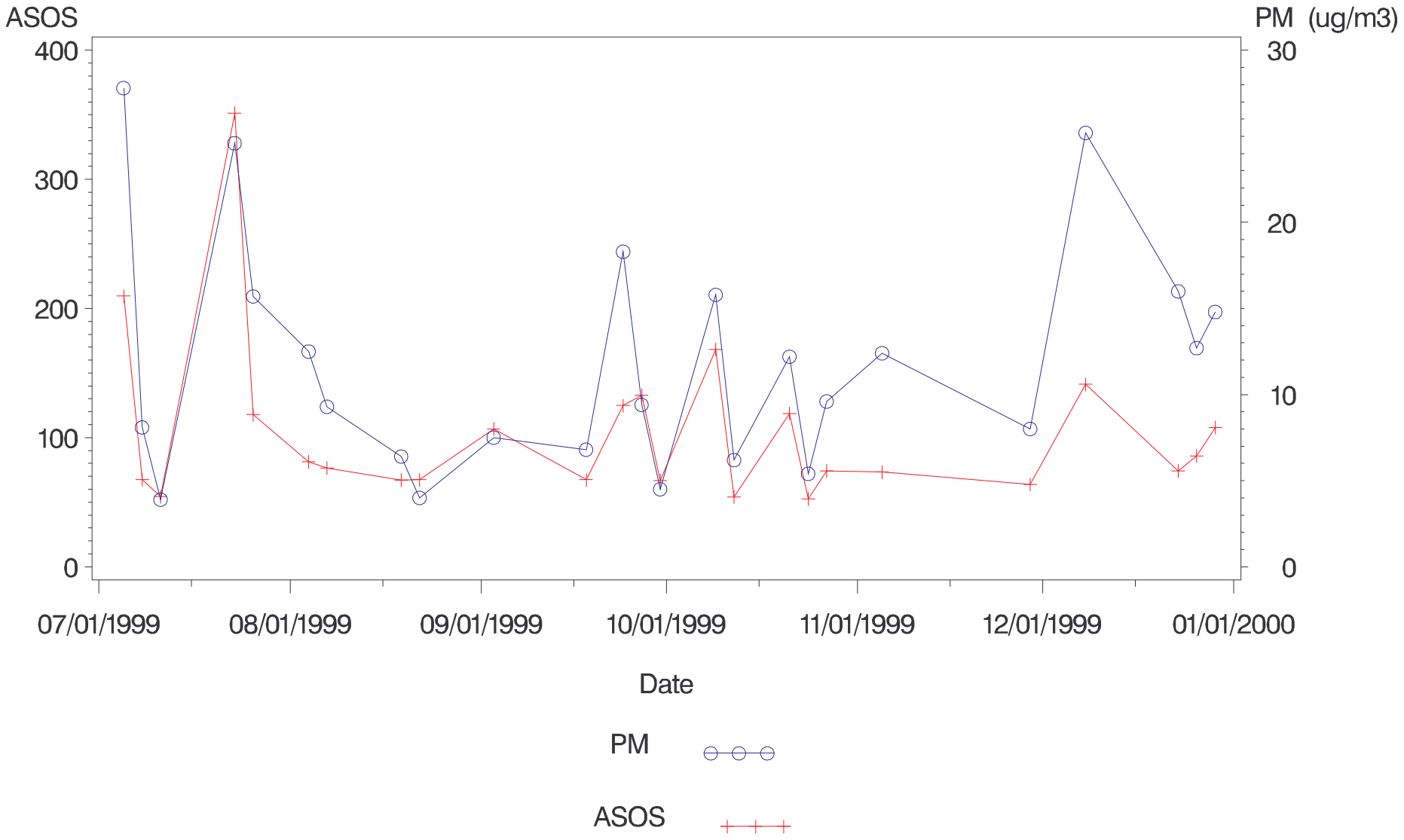
Site Pair: ASOS = JFK , PM = 360810097

ASOS and PM Fine Over Time



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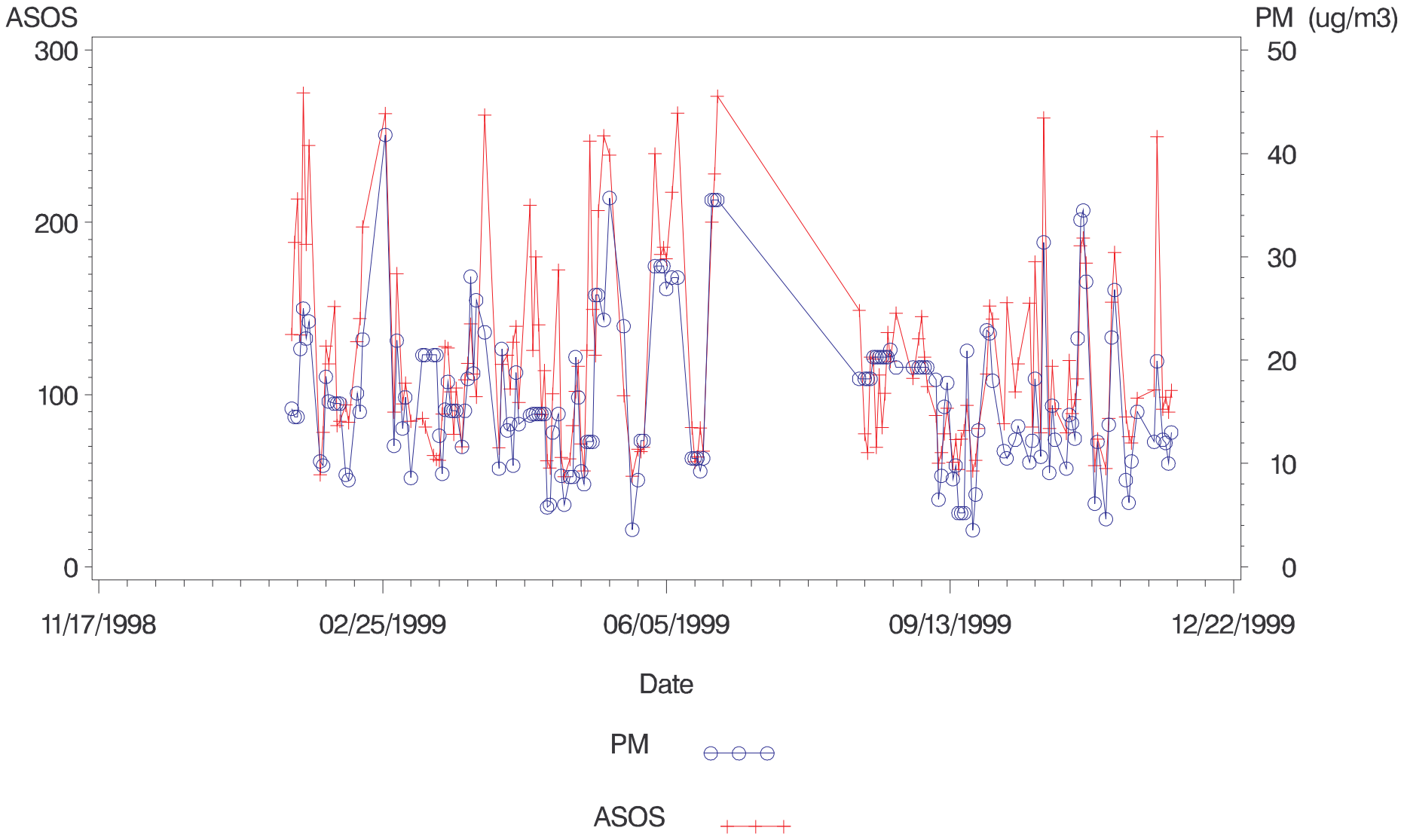
Site Pair: ASOS = IND , PM = 180970083

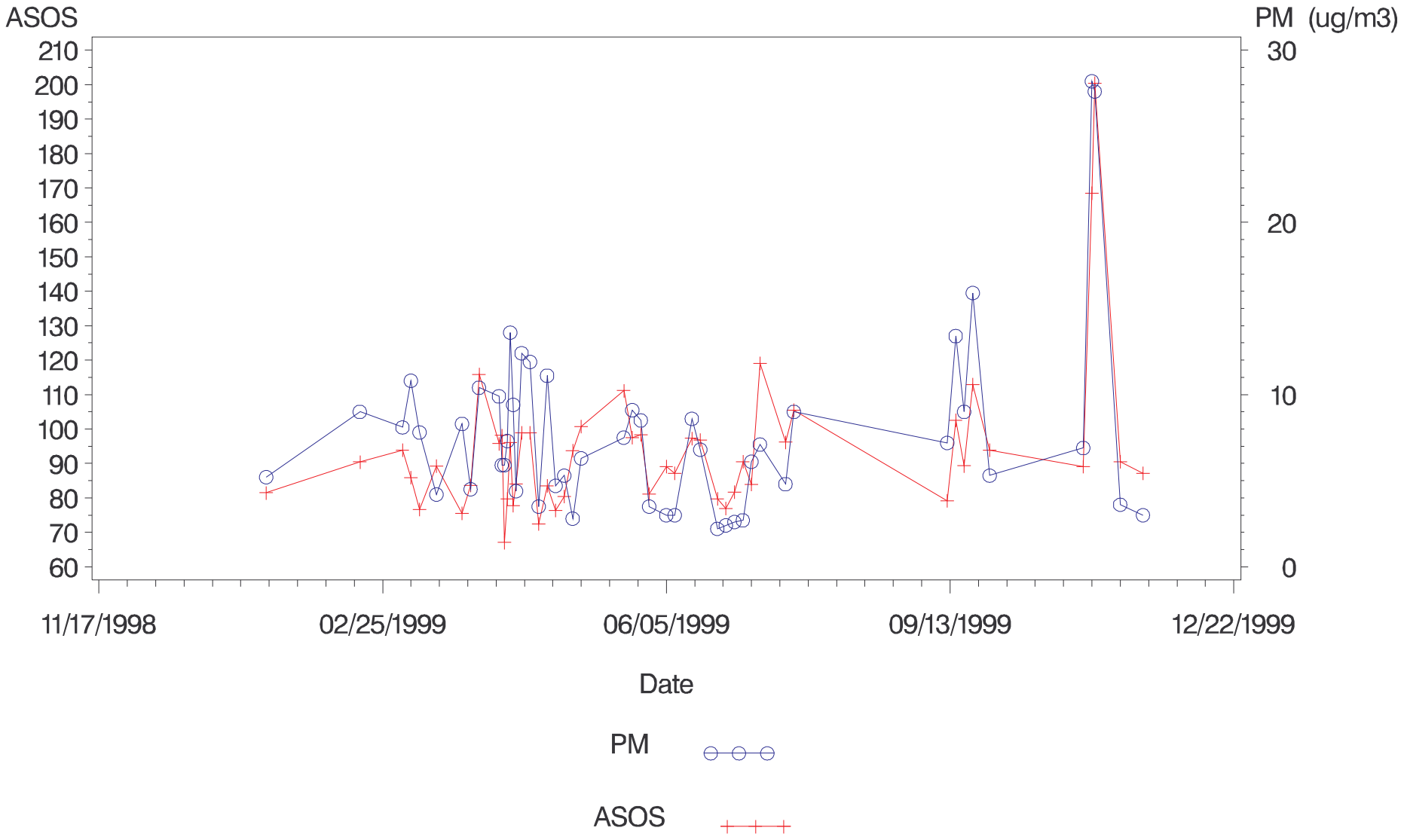
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = GEG , PM = 530630047

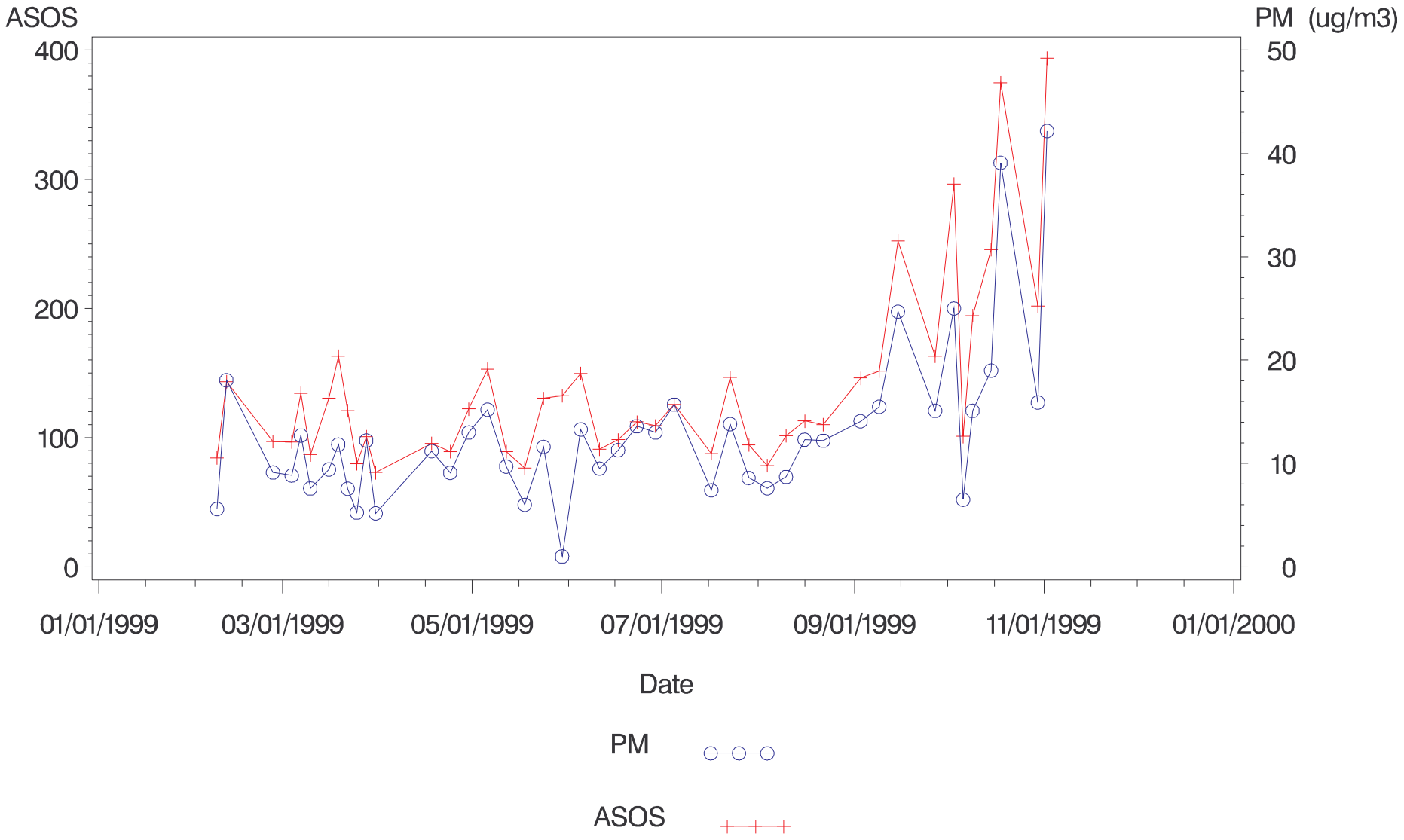
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = FAT , PM = 060195001

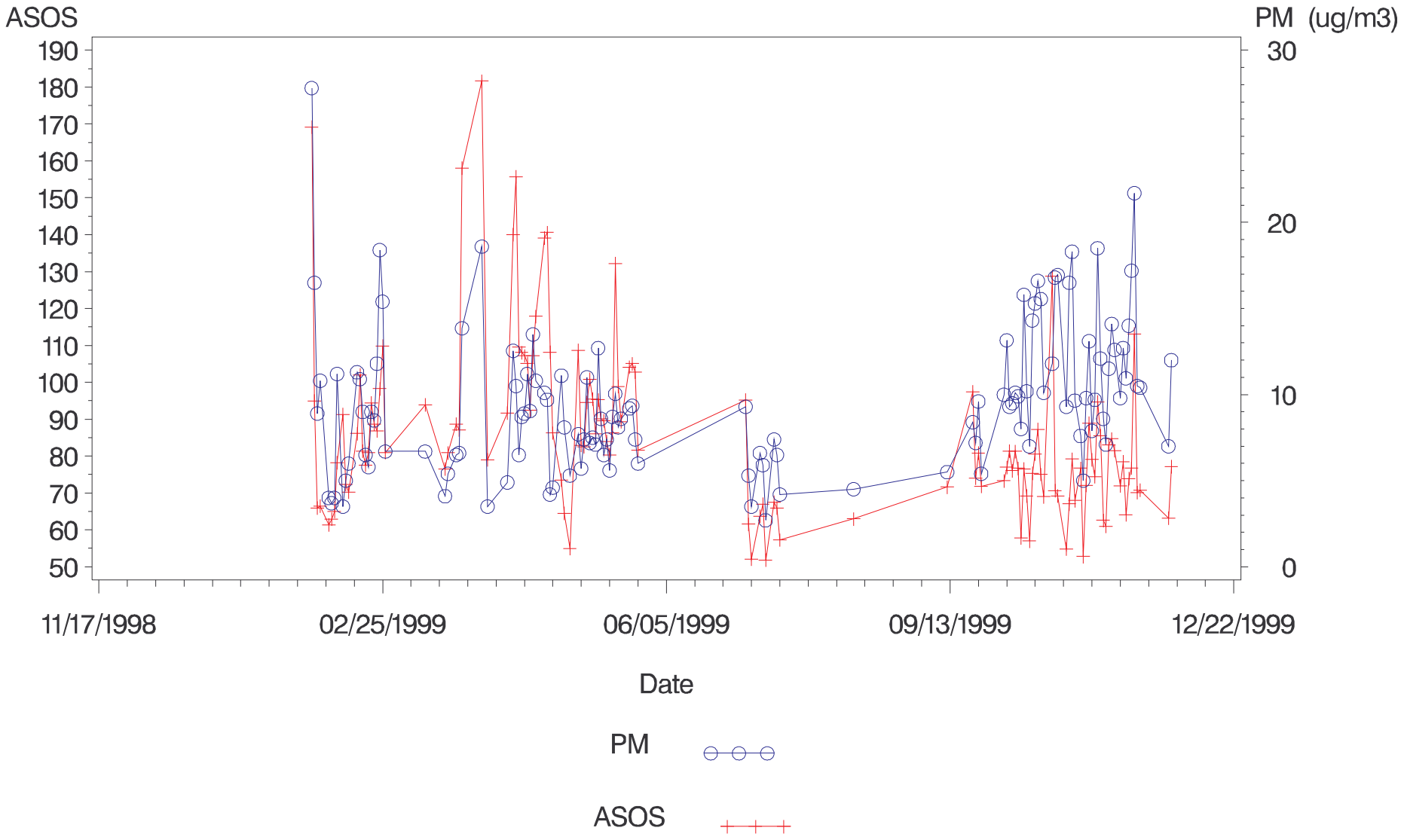
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = ELP , PM = 481410044

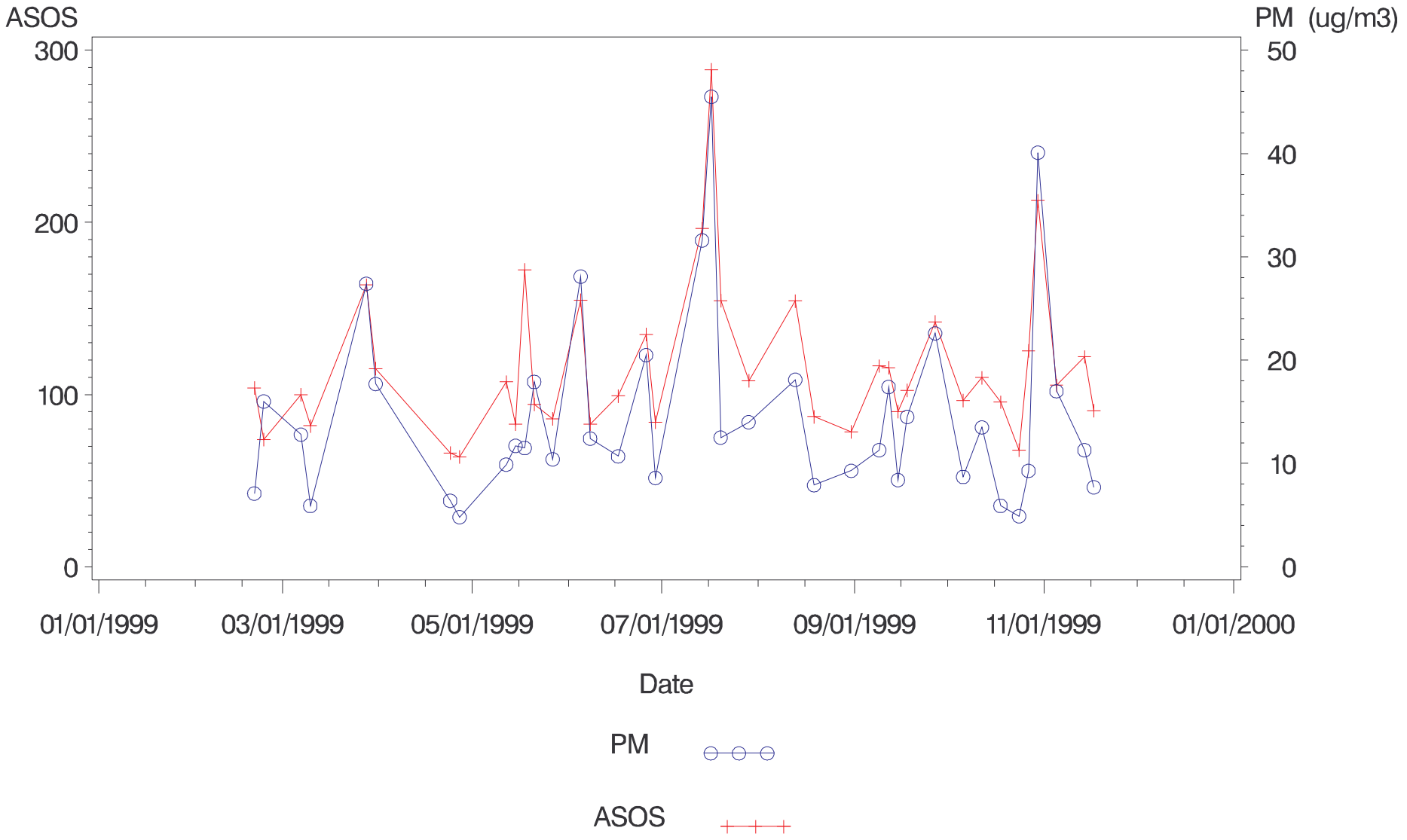
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = DTW , PM = 261630036

ASOS and PM Fine Over Time



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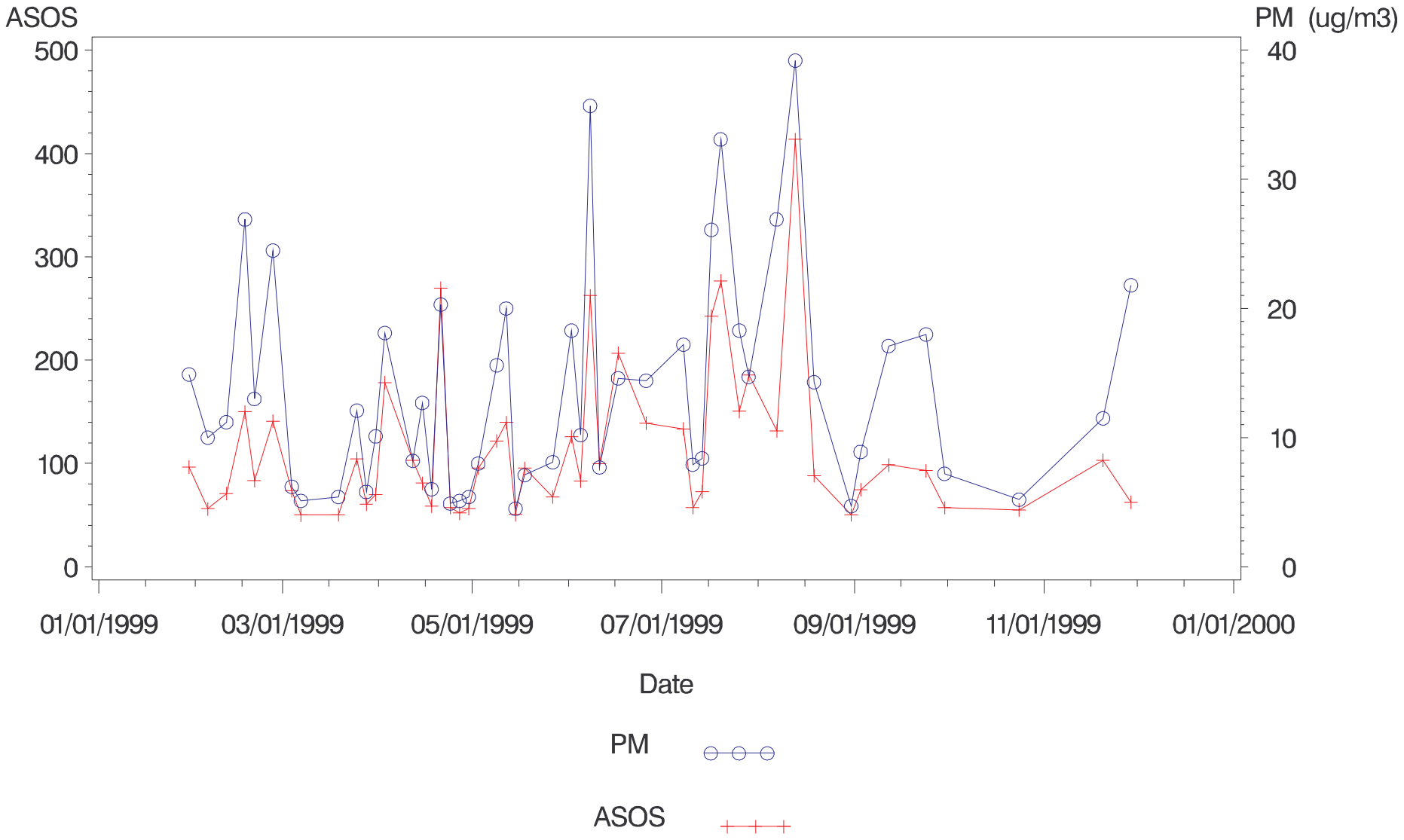
Site Pair: ASOS = DCA , PM = 510591004

ASOS and PM Fine Over Time



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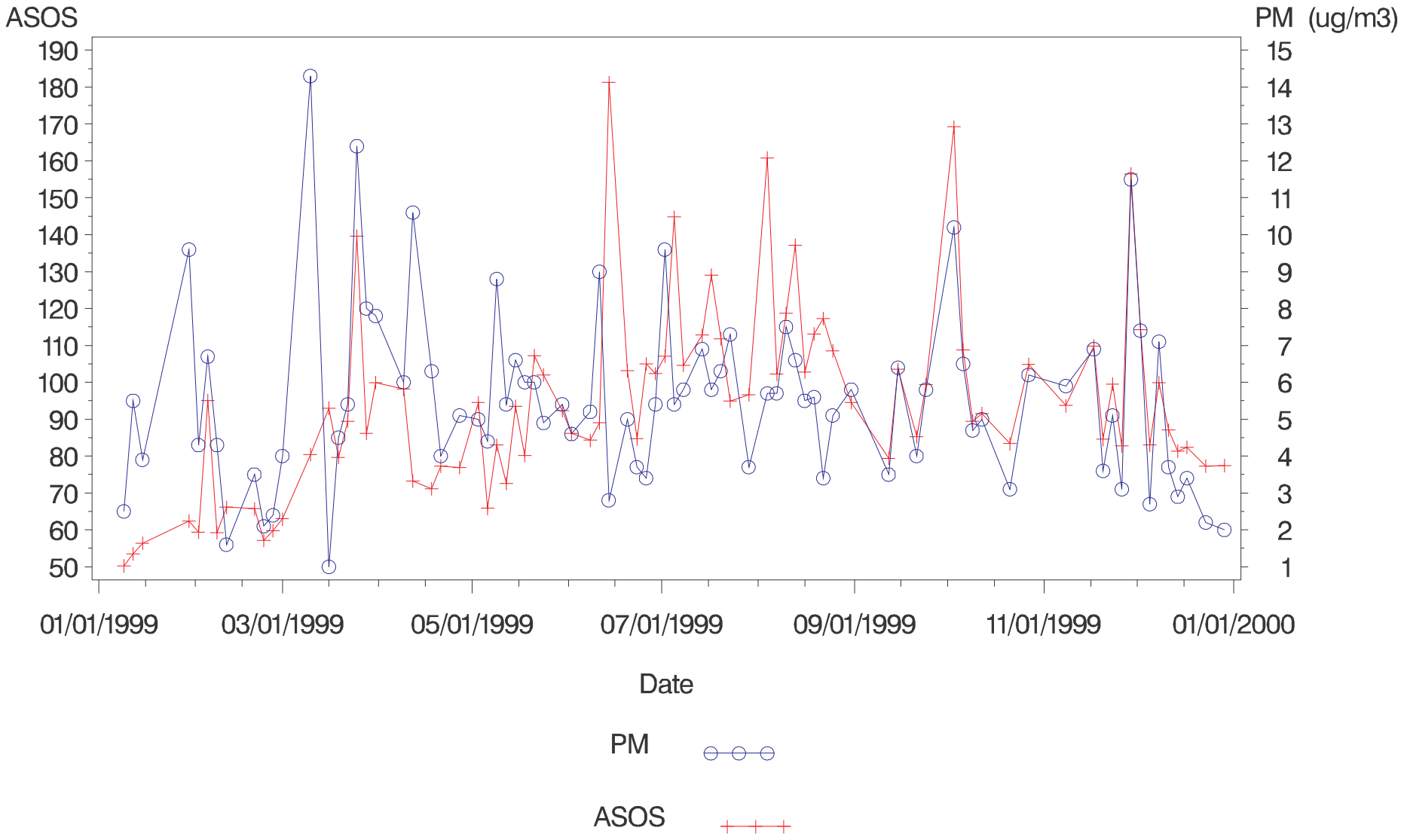
Site Pair: ASOS = CYS , PM = 560210001

ASOS and PM Fine Over Time



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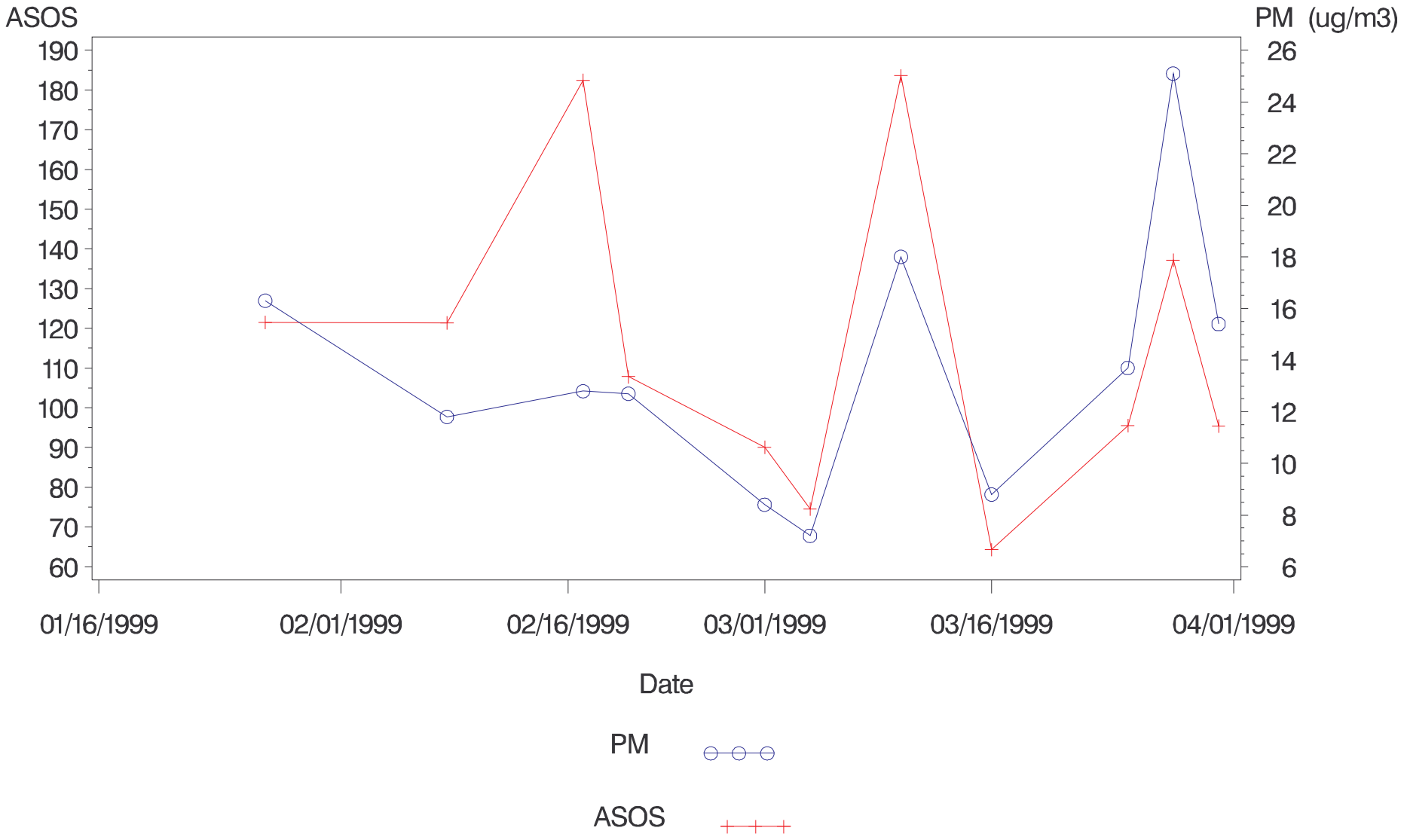
Site Pair: ASOS = CVG , PM = 211170007

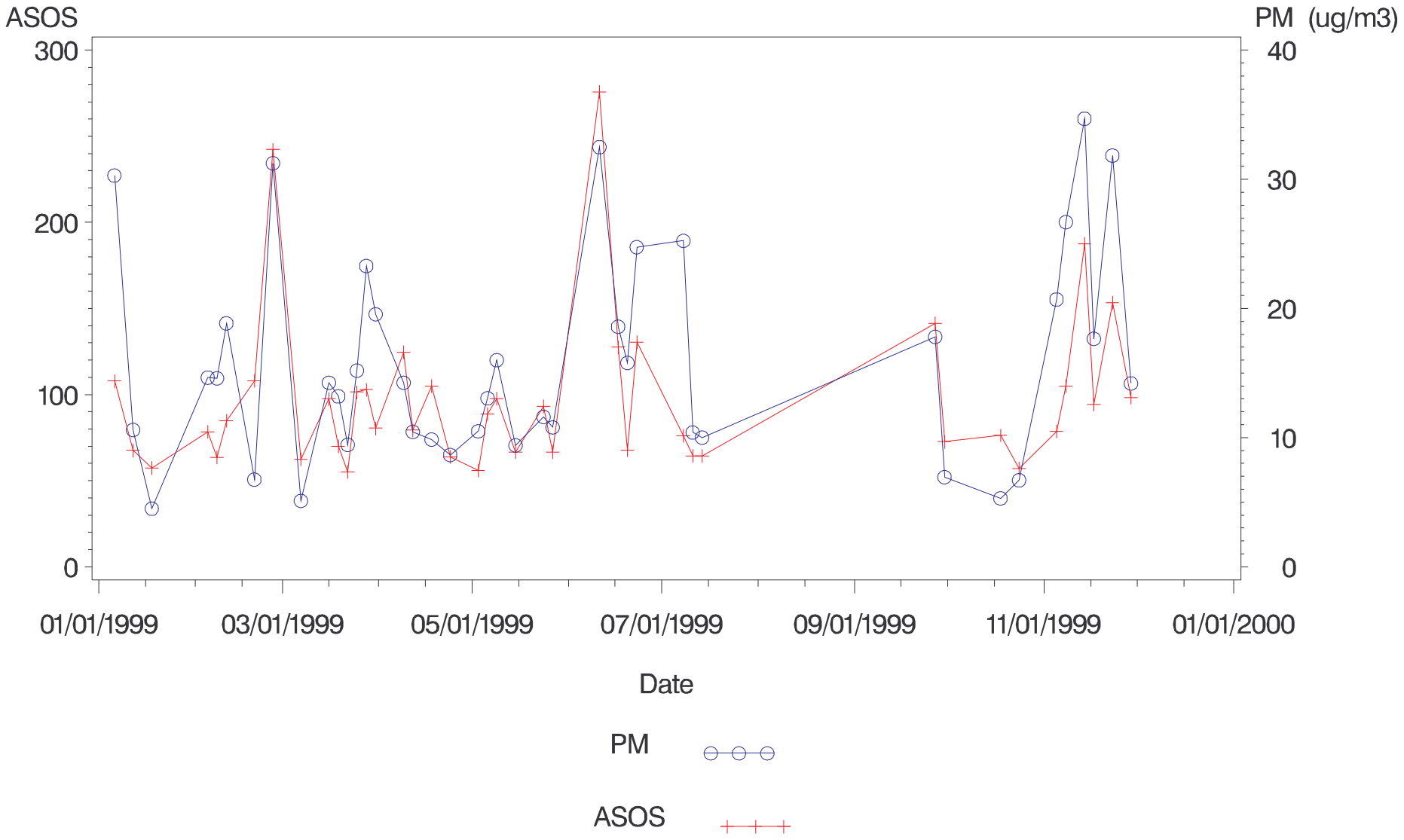
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = CRW , PM = 540391005

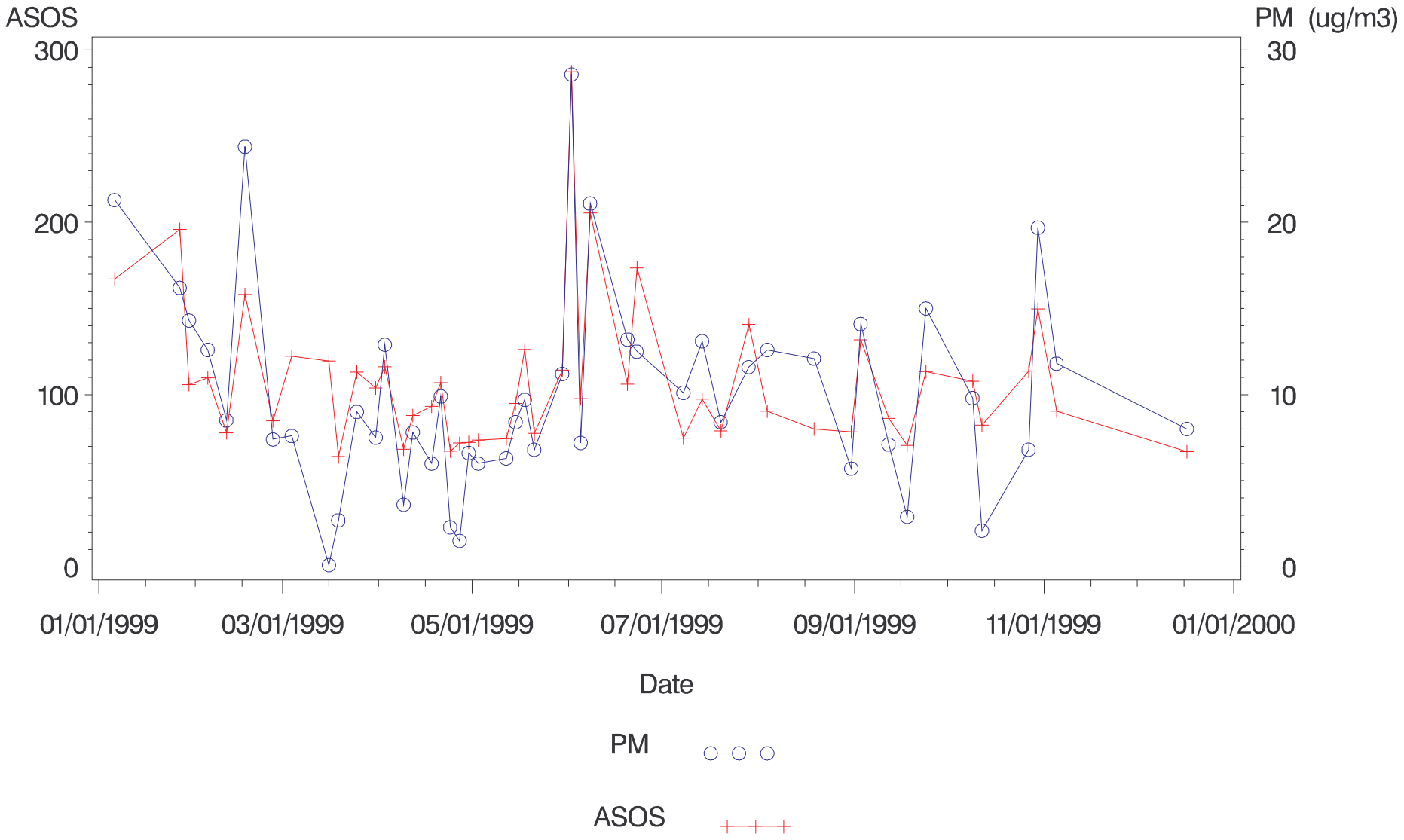
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = CON , PM = 330130003

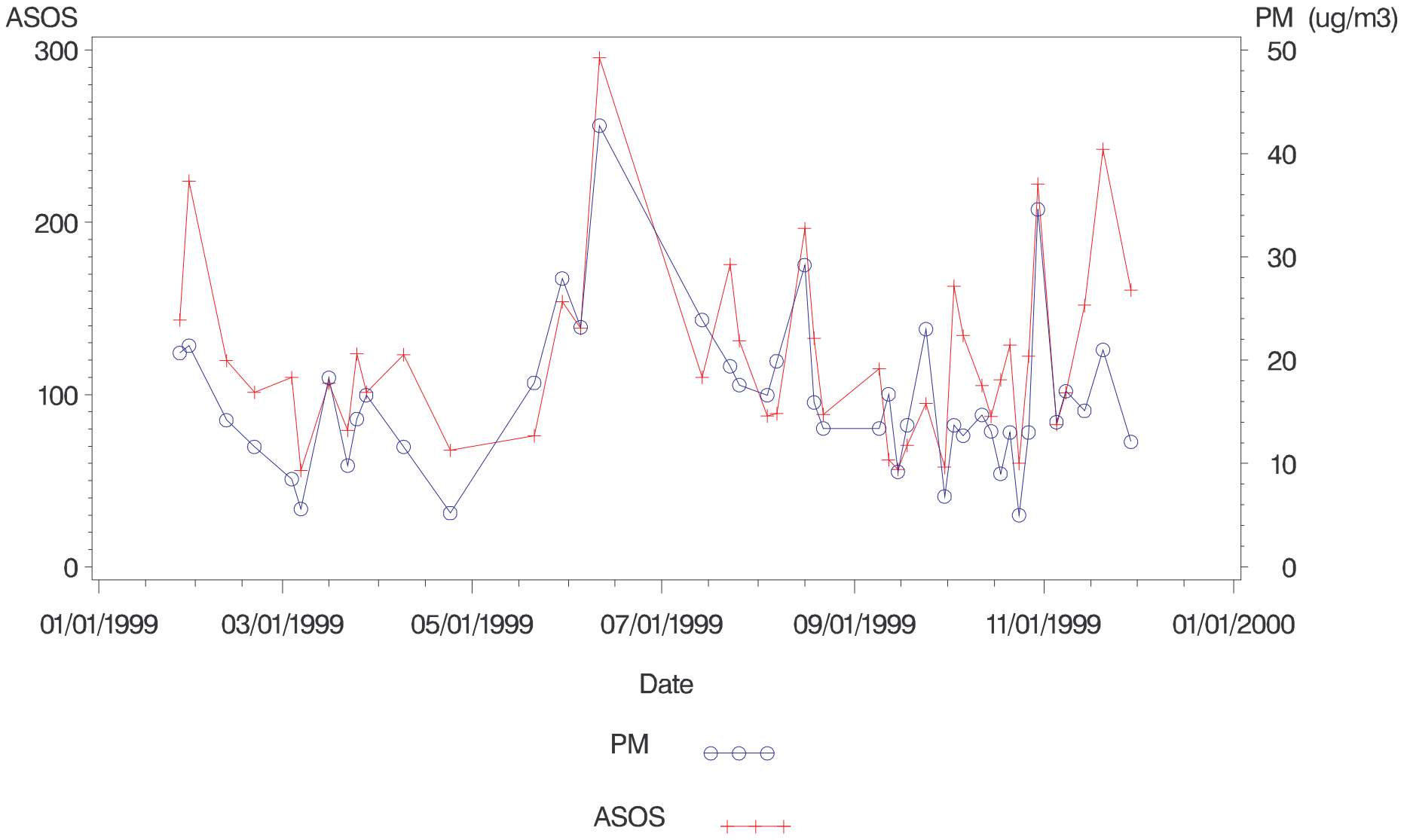
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = CMH , PM = 390490081

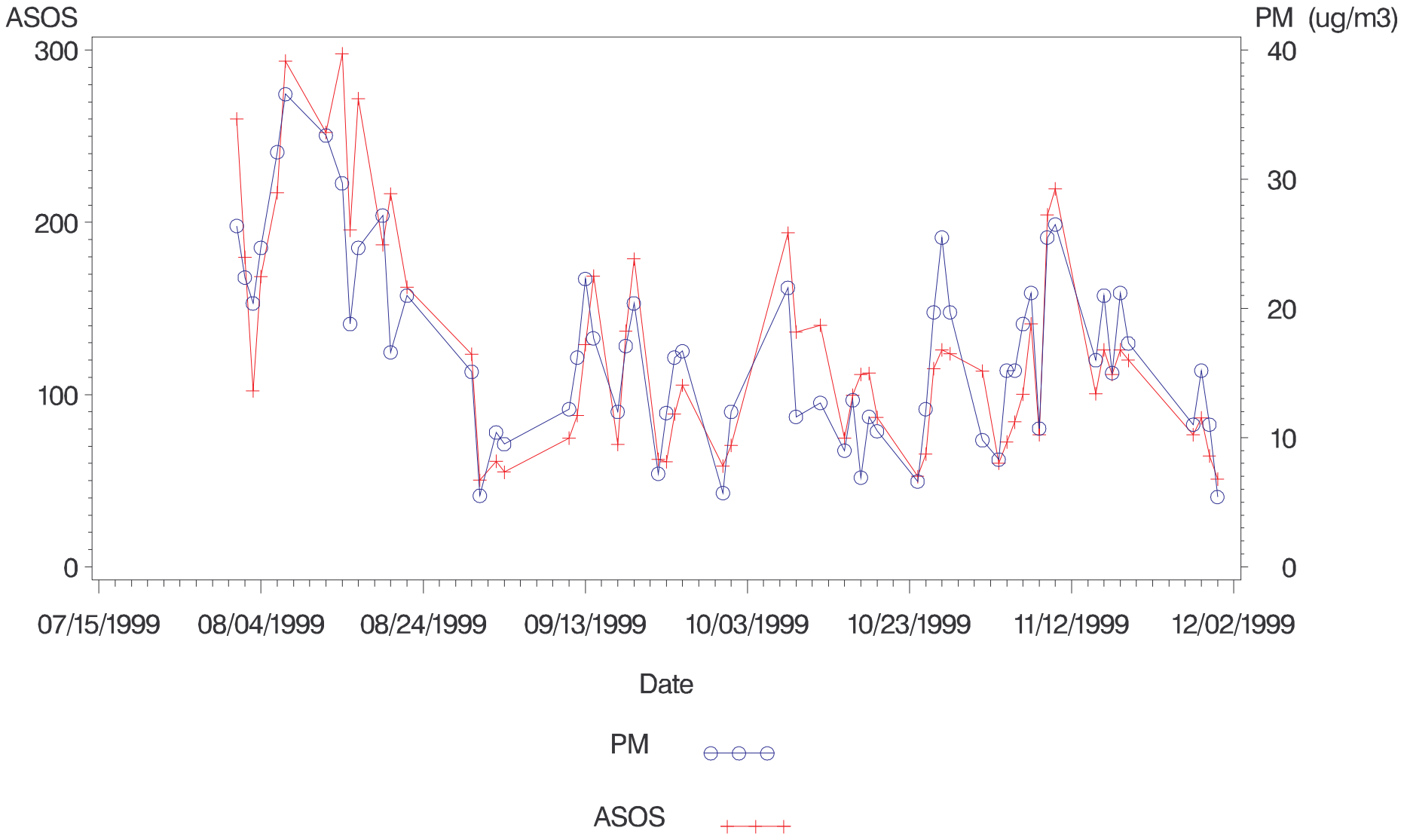
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = CLT , PM = 371190041

ASOS and PM Fine Over Time



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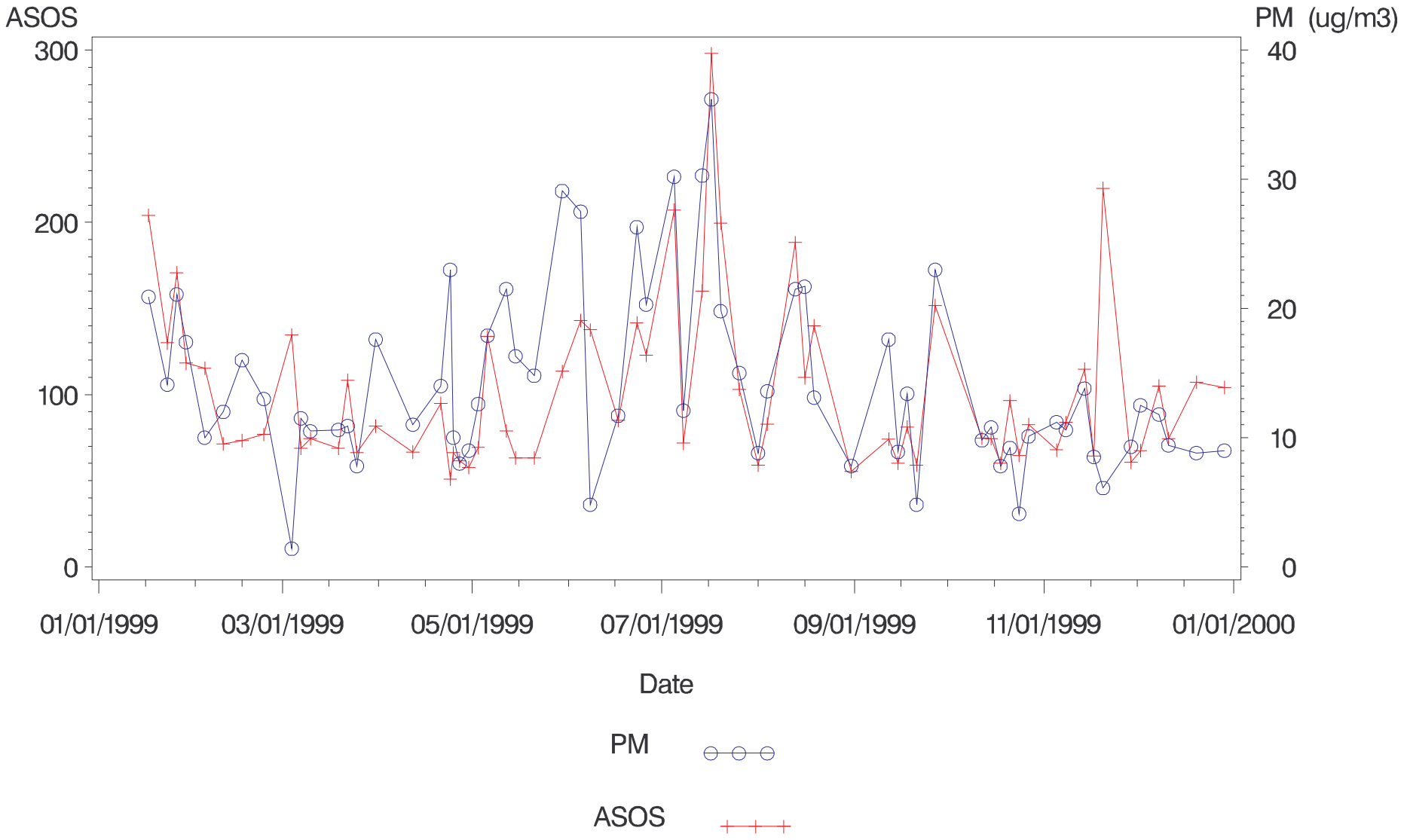
Site Pair: ASOS = CLE , PM = 390351002

ASOS and PM Fine Over Time



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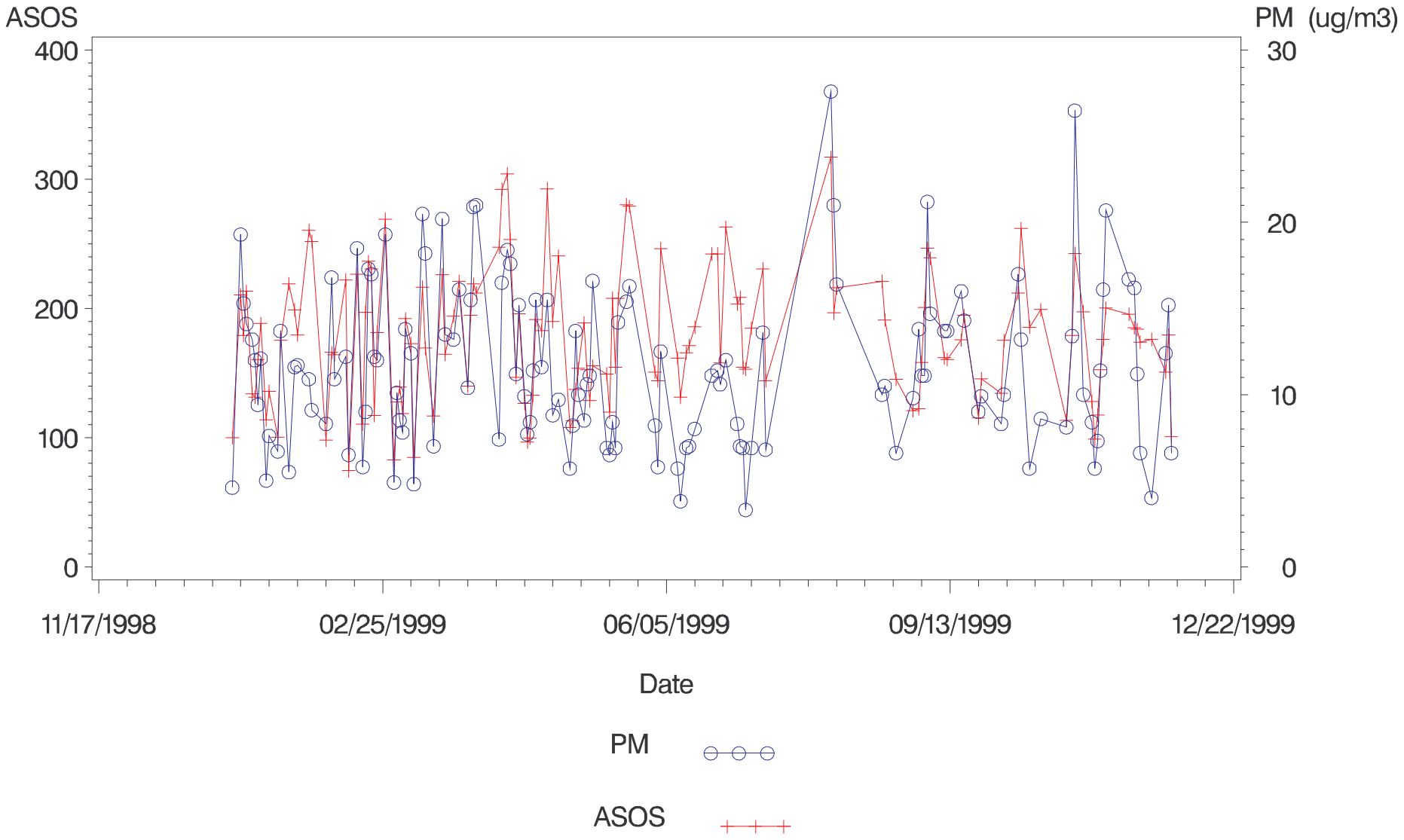
Site Pair: ASOS = CHS , PM = 450190049

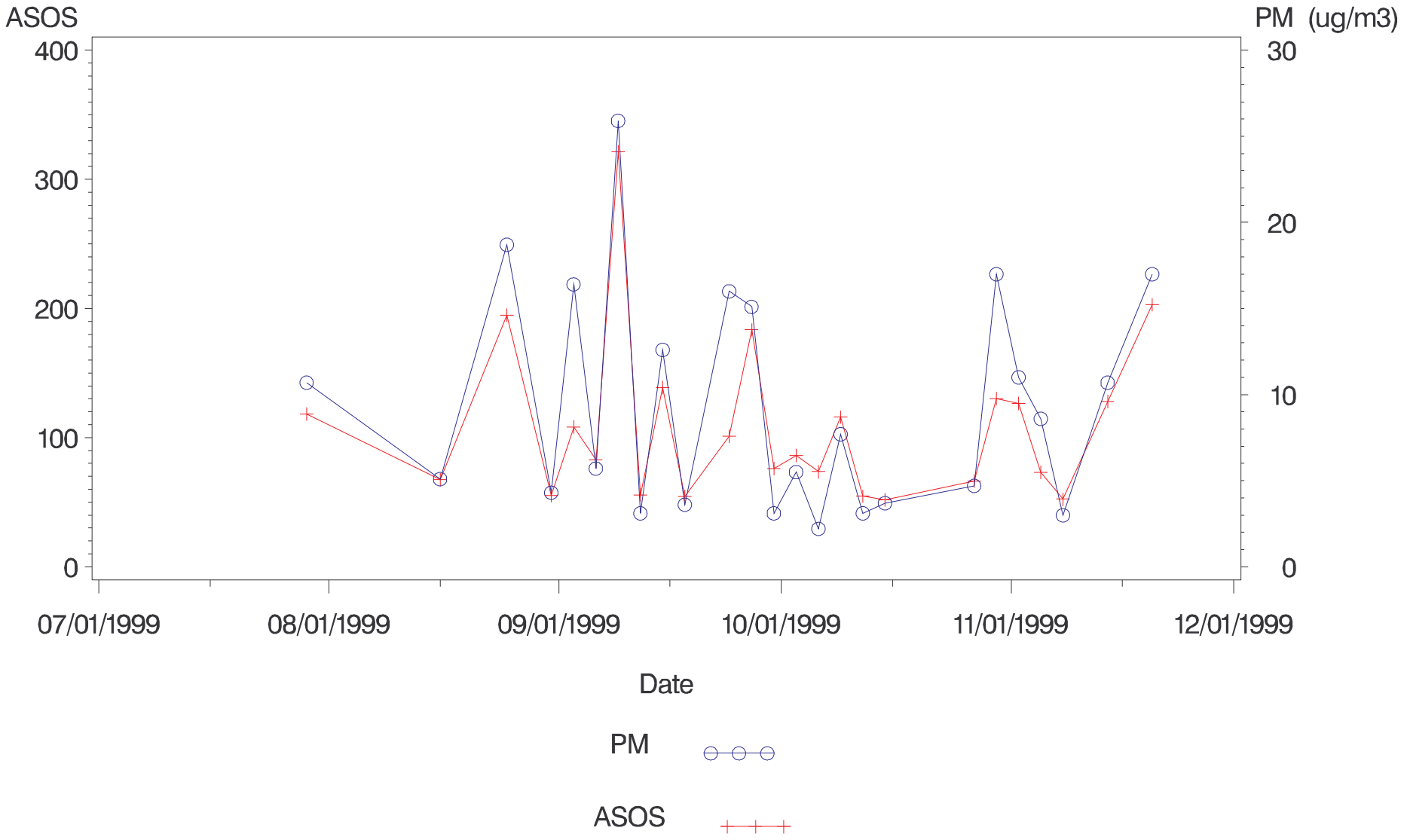
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = BTV , PM = 500070012

ASOS and PM Fine Over Time



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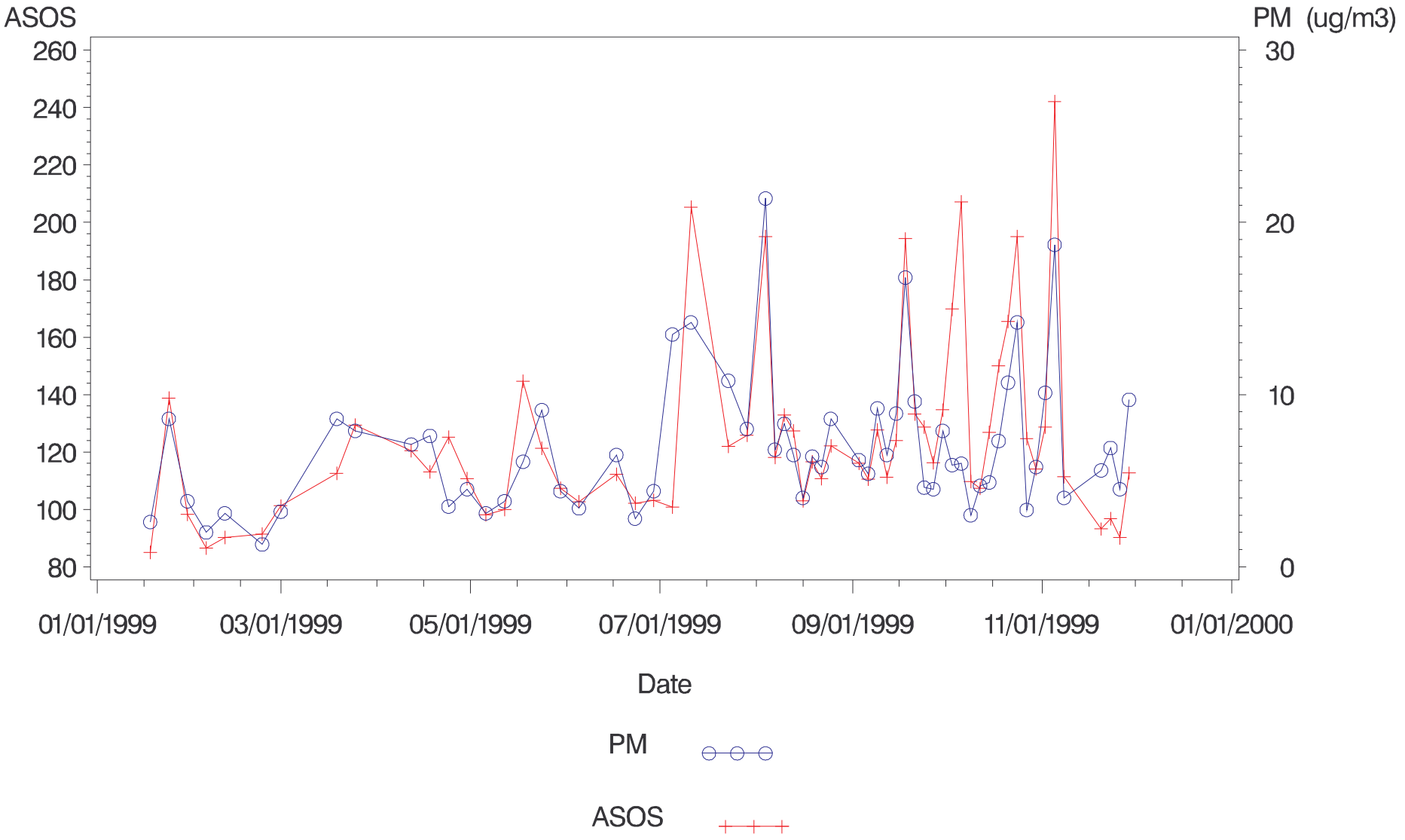
Site Pair: ASOS = BOI , PM = 160010017

ASOS and PM Fine Over Time



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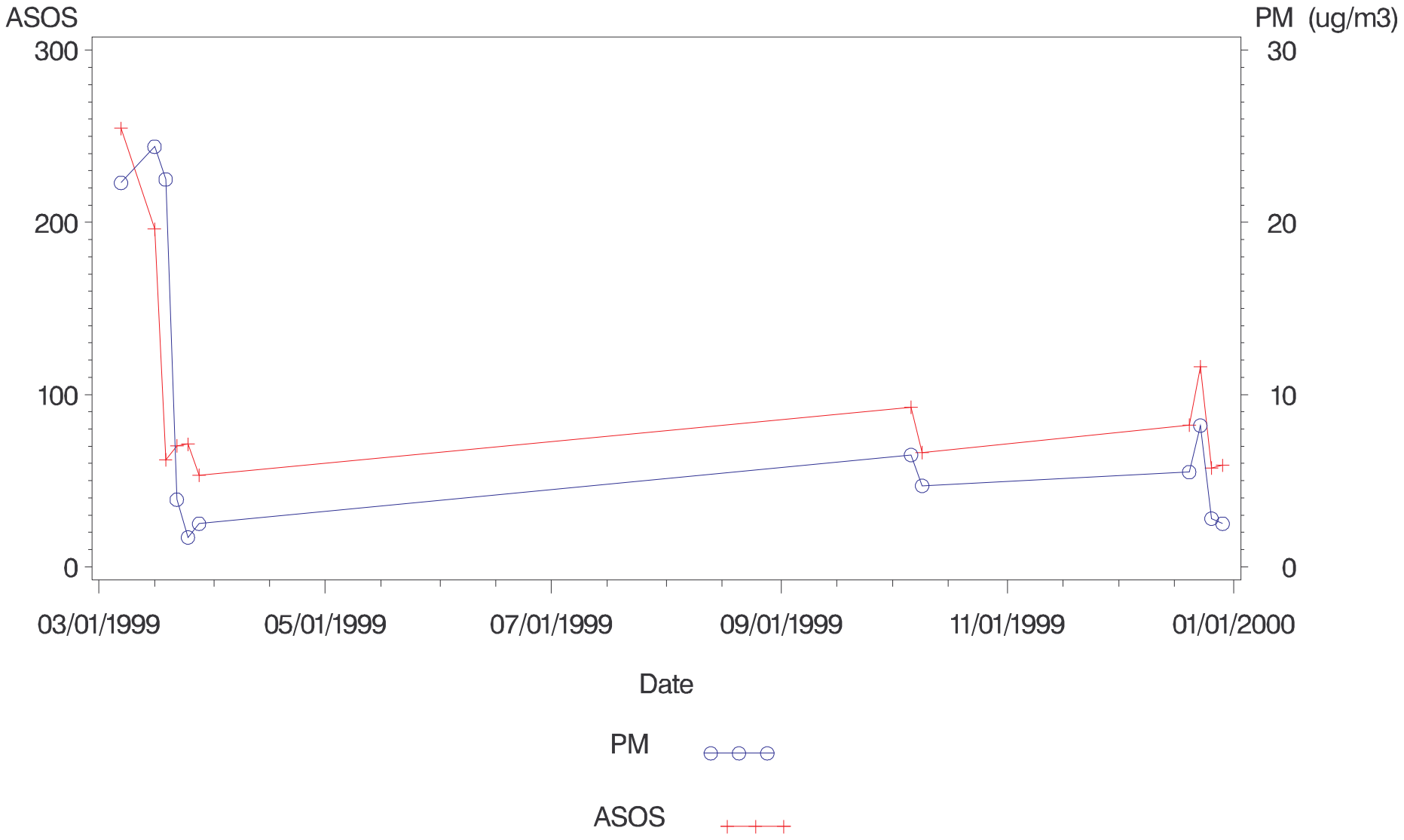
Site Pair: ASOS = BIS , PM = 380150003

ASOS and PM Fine Over Time



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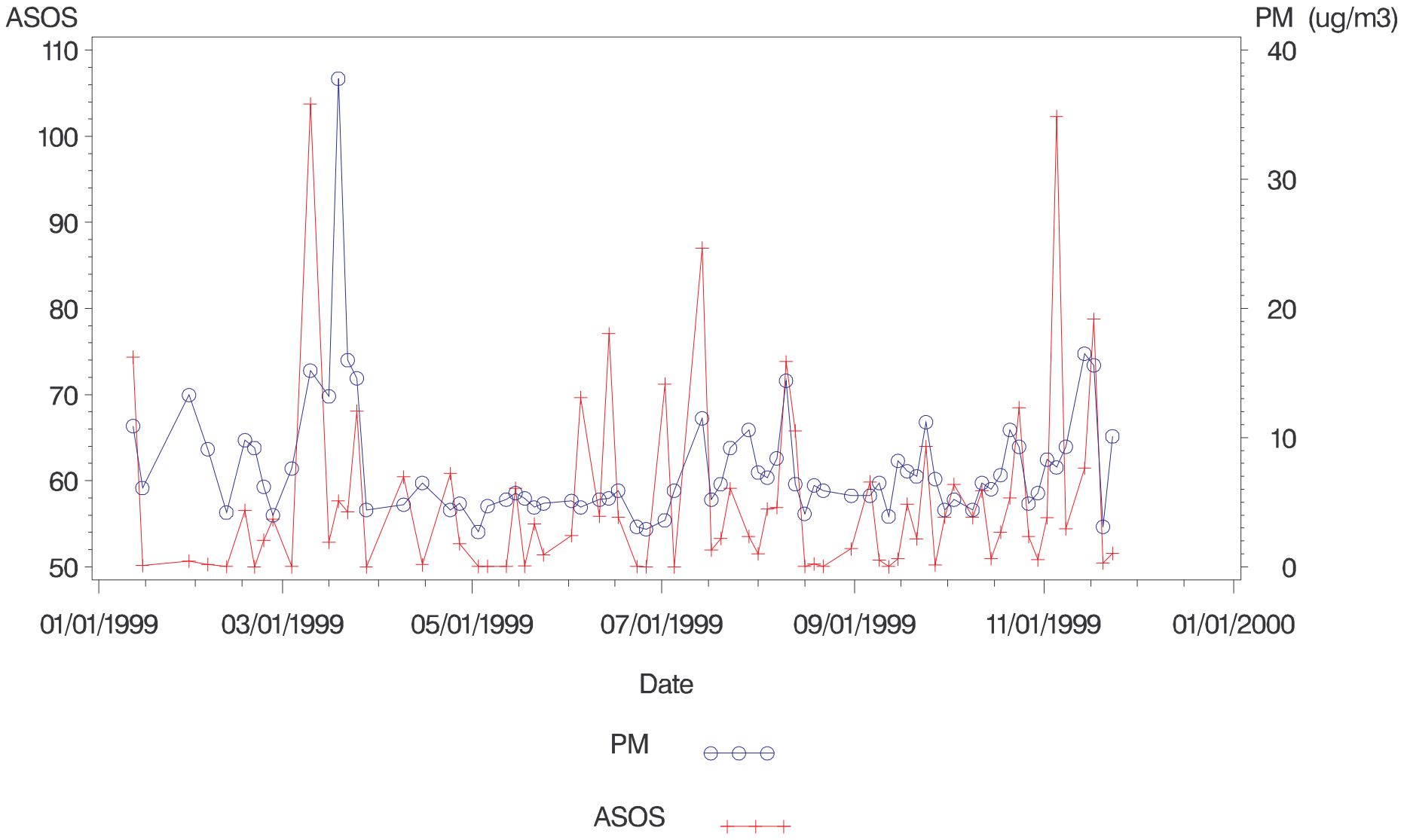
Site Pair: ASOS = BIL , PM = 301111065

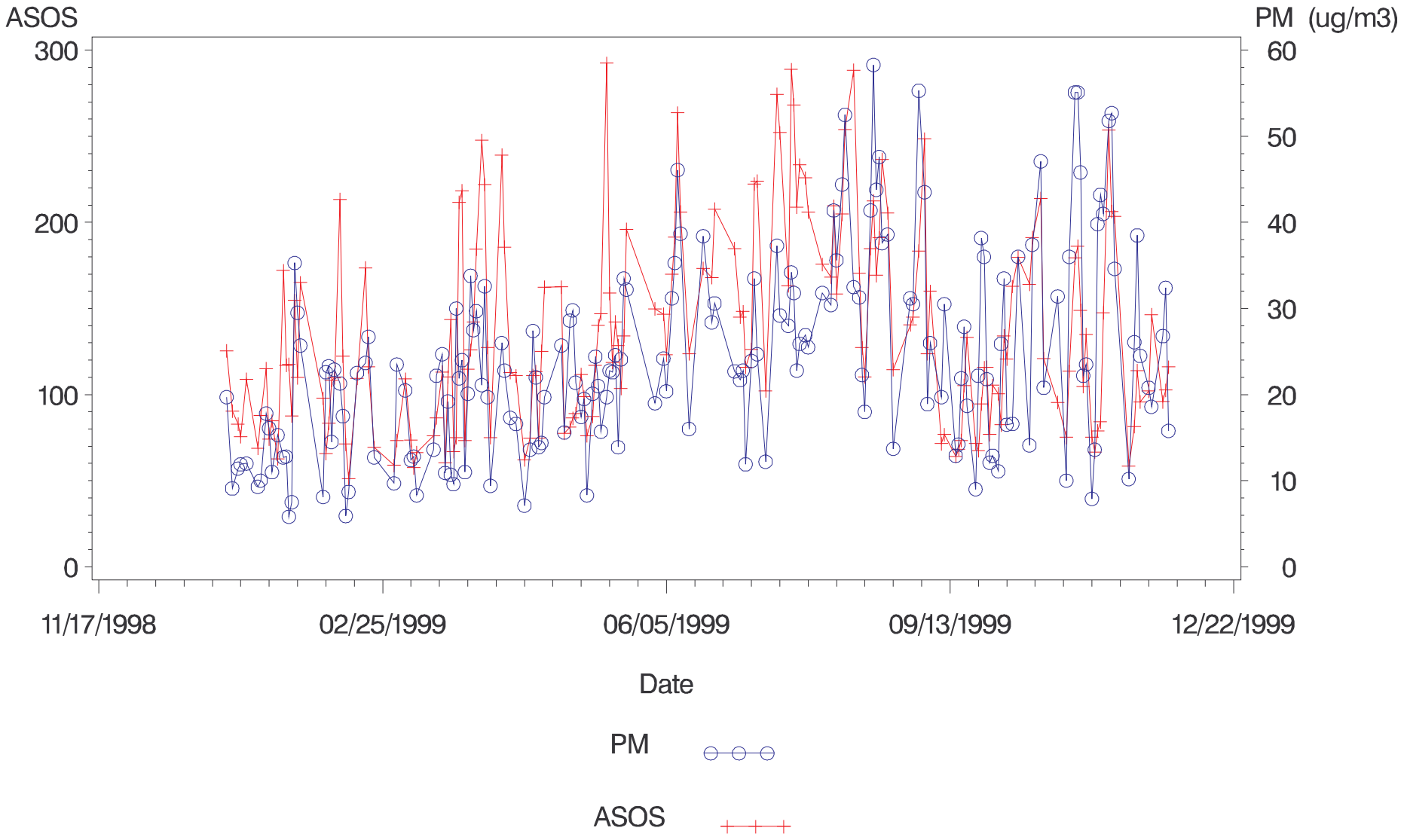
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = BHM , PM = 010730023

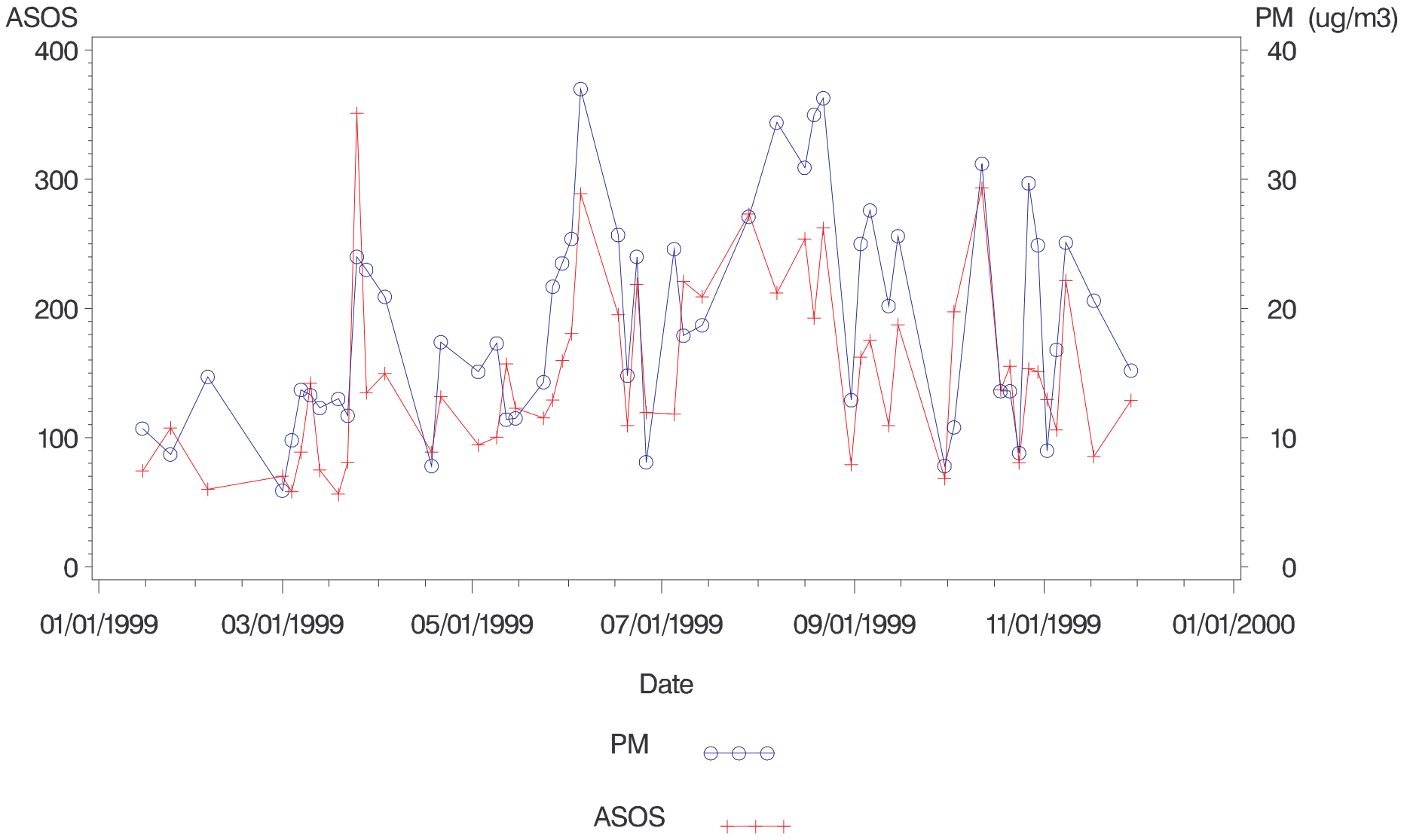
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = ATL , PM = 131211001

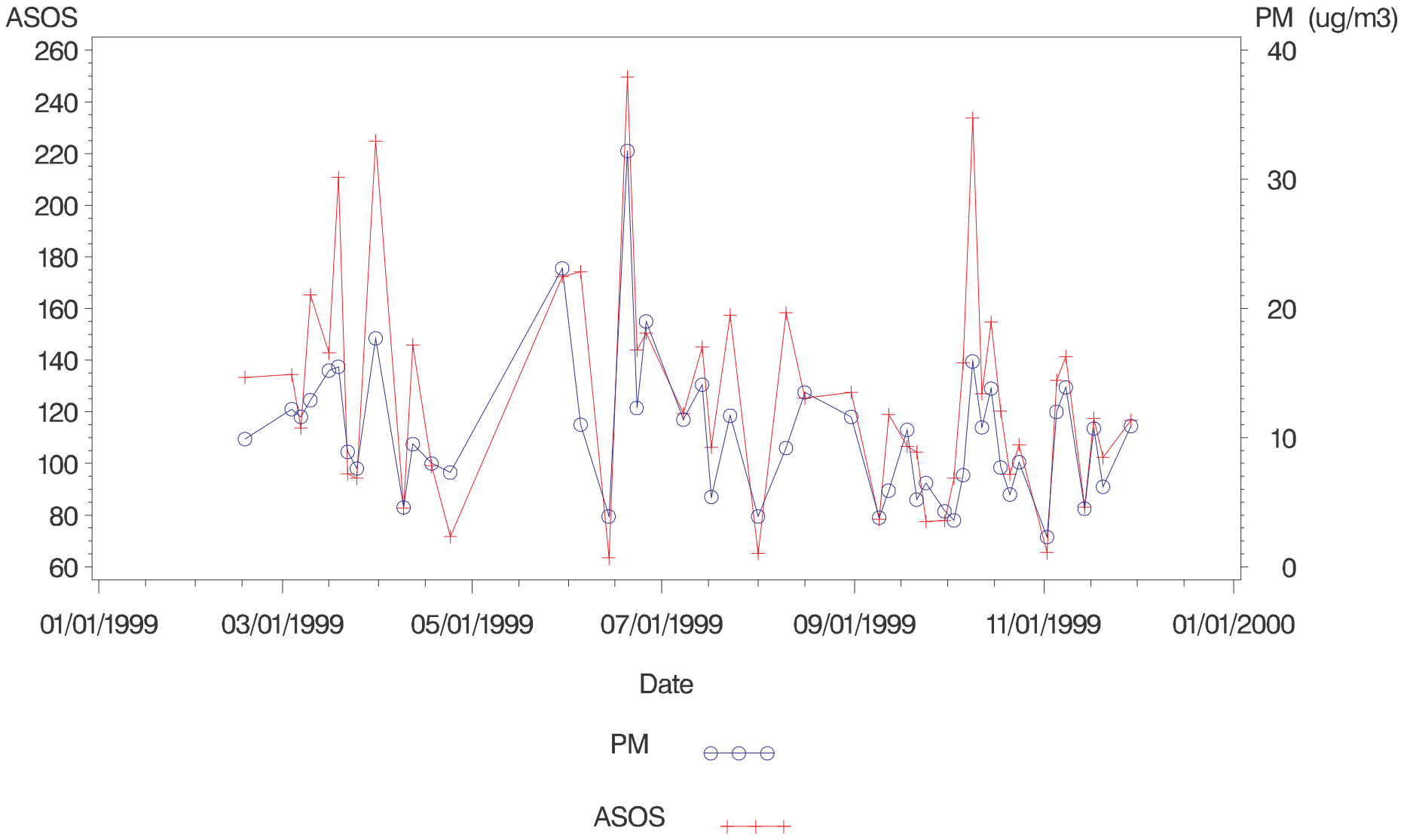
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = ALO , PM = 190130008

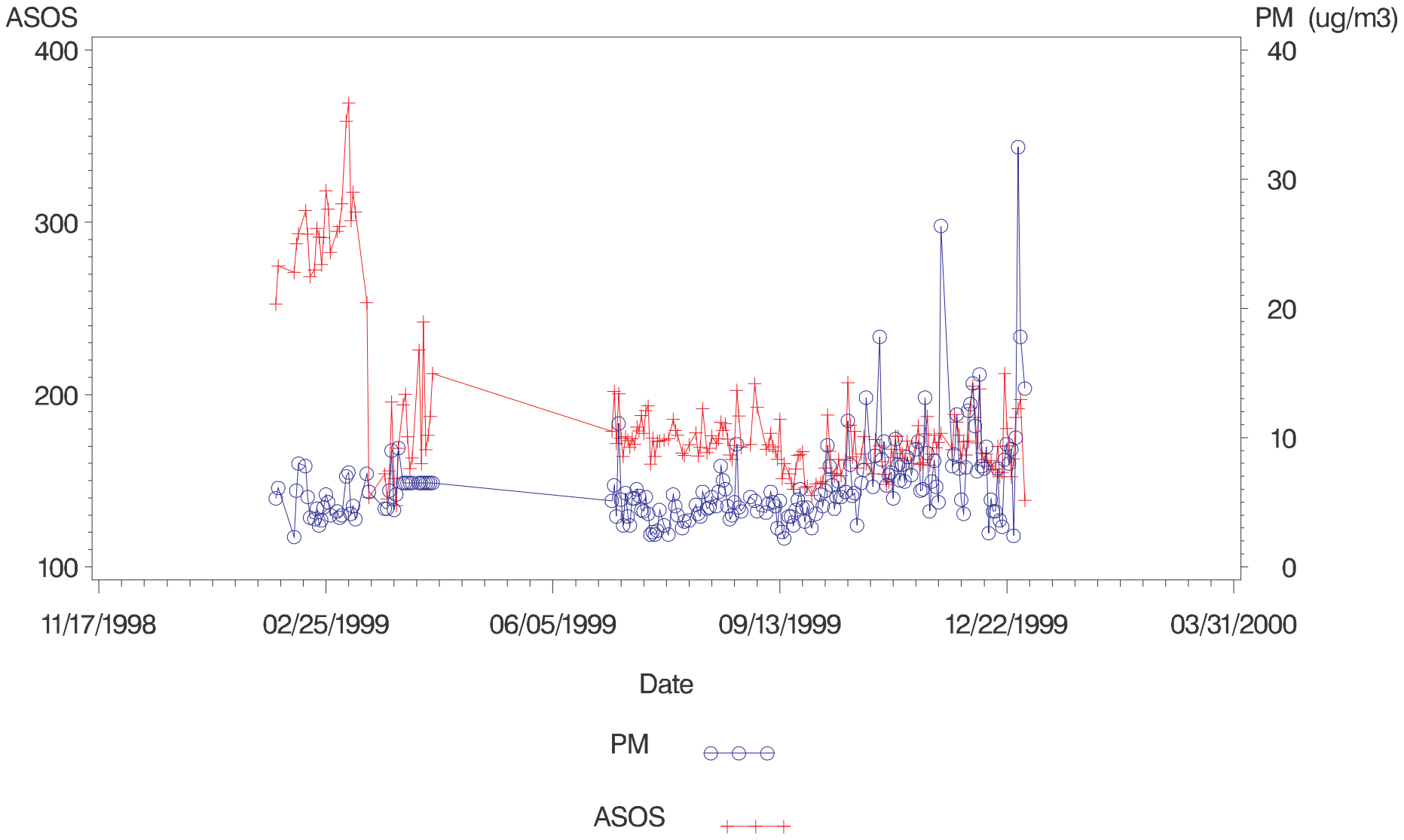
ASOS and PM Fine Over Time



19MAR02:10:00:57

Site Pair: ASOS = ABQ , PM = 350010024

ASOS and PM Fine Over Time



19MAR02:10:00:57

Appendix F - Grouping of IMPROVE and CASTnet sites with paired ASOS sites and values of $[CM]$, $[X_{SO4,NO3}]$, $[X_{OC}]$, and $[X_{SOIL}]$ for each matched group.

Season		ASOS site	IMPROVE & CASTNET site(s)	avg coarse mass conc [cm]	avg_%sulfate + nitrate Xsulfate+nitrate	avg_%OMC Xomc	avg_%soil Xsoil	rayleigh
spring	BIL	Billings	BRID, YELL	2.899	0.322	0.388	0.248	10
summer				3.047	0.342	0.449	0.154	10
autumn				2.997	0.227	0.468	0.255	10
winter				0.550	0.466	0.422	0.058	10
spring	CYS	Cheyenne	ROMO	3.231	0.379	0.323	0.251	10
summer				1.712	0.374	0.448	0.127	10
autumn				3.218	0.304	0.409	0.247	10
winter				1.409	0.430	0.400	0.112	10
spring	SEA	Seattle	MORA	3.263	0.459	0.401	0.078	10
summer				2.437	0.444	0.462	0.033	10
autumn				2.289	0.348	0.530	0.041	10
winter				1.174	0.332	0.523	0.043	10
spring	PDX	Portland	MORA	3.263	0.459	0.401	0.078	10
summer				2.437	0.444	0.462	0.033	10
autumn				2.289	0.348	0.530	0.041	10
winter				1.174	0.332	0.523	0.043	10
spring	GEG	Spokane	MORA, GLAC	4.362	0.414	0.412	0.107	10
summer				10.687	0.285	0.480	0.170	10
autumn				5.253	0.256	0.570	0.089	10
winter				1.650	0.272	0.567	0.054	10
spring	MFR	Medford	CRLA	2.394	0.274	0.415	0.202	10
summer				8.510	0.219	0.502	0.212	10
autumn				2.323	0.189	0.540	0.199	10
winter				1.617	0.200	0.382	0.197	10
spring	SFO	San Franciso	PORE	14.562	0.693	0.205	0.075	10
summer				9.412	0.702	0.250	0.033	10
autumn				7.679	0.686	0.240	0.045	10
winter				7.009	0.437	0.465	0.035	10
spring	FAT	Fresno	PINN, SEQU	6.305	0.423	0.412	0.109	10
summer				8.164	0.412	0.434	0.103	10
autumn				9.145	0.443	0.406	0.094	10
winter				3.640	0.495	0.390	0.049	10
spring		Los Angeles	SAGO	6.446	0.618	0.218	0.122	10
summer				7.704	0.512	0.351	0.088	10
autumn				7.307	0.445	0.266	0.237	10

winter				5.300	0.346	0.288	0.290	10
spring	LAS	Las Vegas	BRCA	5.712	0.368	0.324	0.274	10
summer				4.170	0.498	0.291	0.168	10
autumn				3.128	0.406	0.328	0.212	10
winter				1.058	0.562	0.321	0.070	10
spring	PHX	Phoenix	CHIR, TONT	8.488	0.355	0.264	0.336	10
summer				4.199	0.497	0.284	0.171	10
autumn				6.875	0.448	0.303	0.196	10
winter				4.141	0.361	0.386	0.180	10
spring	ABQ	Albuquerque	BAND, PEFO	4.998	0.298	0.308	0.345	10
summer				2.656	0.446	0.321	0.177	10
autumn				2.674	0.404	0.359	0.178	10
winter				1.735	0.307	0.428	0.171	10
spring	ELP	El Paso	CHIR, GUMO	8.796	0.297	0.241	0.430	10
summer				4.670	0.488	0.218	0.263	10
autumn				7.316	0.472	0.259	0.232	10
winter				7.292	0.373	0.277	0.296	10
spring	SAT	San Antonio	BIBE	6.854	0.541	0.215	0.215	10
summer				8.537	0.461	0.256	0.256	10
autumn				9.119	0.521	0.210	0.229	10
winter				6.151	0.502	0.263	0.186	10
spring	OKC	Oklahoma City	UPBU	7.529	0.641	0.236	0.082	10
summer				15.740	0.463	0.317	0.187	10
autumn				7.955	0.477	0.389	0.094	10
winter				4.880	0.648	0.266	0.042	10
spring	MSY	New Orleans	SIPS, UPBU, SIK570	8.725	0.603	0.287	0.064	10
summer				12.040	0.538	0.286	0.134	10
autumn				8.465	0.472	0.380	0.065	10
winter				5.582	0.581	0.444	0.036	10
spring	LIT	Little Rock	SIPS, UPBU, SIK570	8.725	0.603	0.287	0.064	10
summer				12.040	0.538	0.286	0.134	10
autumn				8.465	0.472	0.380	0.065	10
winter				5.582	0.581	0.444	0.036	10
spring	BHM	Birmingham	SIPS, UPBU, SIK570	8.725	0.603	0.287	0.064	10
summer				12.040	0.538	0.286	0.134	10
autumn				8.465	0.472	0.380	0.065	10
winter				5.582	0.581	0.444	0.036	10
spring	ATL	Altanta	GRSM, SIPS	7.322	0.586	0.296	0.066	10
summer				8.590	0.644	0.245	0.078	10

autumn				7.962	0.596	0.317	0.044	10
winter				5.216	0.630	0.275	0.041	10
spring	CHS	Charleston	OKEF	8.942	0.604	0.269	0.078	10
summer				7.118	0.566	0.259	0.148	10
autumn				8.252	0.569	0.333	0.054	10
winter				9.524	0.463	0.379	0.081	10
spring	TPA	Tampa	CHAS	8.178	0.641	0.251	0.057	10
summer				7.499	0.521	0.198	0.252	10
autumn				5.787	0.590	0.300	0.038	10
winter				5.496	0.396	0.404	0.104	10
spring	MIA	Miami	CHAS	8.178	0.641	0.251	0.057	10
summer				7.499	0.521	0.198	0.252	10
autumn				5.787	0.590	0.300	0.038	10
winter				5.496	0.396	0.404	0.104	10
spring	DCA	Washington, DC	WASH	5.238	0.443	0.364	0.078	10
summer				5.351	0.649	0.233	0.046	10
autumn				6.144	0.533	0.311	0.064	10
winter				4.587	0.586	0.277	0.046	10
spring	MCO	Orlando	CHAS	8.178	0.641	0.251	0.057	10
summer				7.499	0.521	0.198	0.252	10
autumn				5.787	0.590	0.300	0.038	10
winter				5.496	0.396	0.404	0.104	10
spring	JFK	New York	BRIG	13.303	0.656	0.243	0.044	10
summer				10.827	0.703	0.222	0.041	10
autumn				12.129	0.644	0.255	0.038	10
winter				5.827	0.664	0.251	0.025	10
spring	PHL	Philadelphia	BRIG	13.303	0.656	0.243	0.044	10
summer				10.827	0.703	0.222	0.041	10
autumn				12.129	0.644	0.255	0.038	10
winter				5.827	0.664	0.251	0.025	10
spring	PWM	Portland	ACAD	5.227	0.511	0.335	0.081	10
summer				3.968	0.566	0.348	0.044	10
autumn				3.332	0.554	0.321	0.063	10
winter				4.011	0.580	0.305	0.060	10
spring	BTV	Burlington	LYBR	1.182	0.545	0.323	0.082	10
summer				1.405	0.563	0.355	0.040	10
autumn				2.560	0.625	0.285	0.044	10
winter				0.793	0.631	0.292	0.031	10
spring	SYR	Syracuse	CTH510, (cm-LYBR)	1.182	0.826	0.226	0.047	10

summer				1.405	0.657	0.245	0.044	10
autumn				2.560	0.718	0.173	0.042	10
winter				0.793	0.804	0.261	0.036	10
spring	CLT	Charlotte	GRSM	4.723	0.569	0.317	0.066	10
summer				8.840	0.660	0.242	0.073	10
autumn				6.949	0.642	0.277	0.037	10
winter				4.148	0.636	0.268	0.044	10
spring	RIC	Richmond	DOSO, GRSM, SHEN, WASH	5.241	0.509	0.349	0.065	10
summer				5.543	0.680	0.230	0.051	10
autumn				5.619	0.604	0.287	0.049	10
winter				3.828	0.593	0.297	0.042	10
spring	RDU	Raleigh	DOSO, GRSM, SHEN, WASH	5.241	0.509	0.349	0.065	10
summer				5.543	0.680	0.230	0.051	10
autumn				5.619	0.604	0.287	0.049	10
winter				3.828	0.593	0.297	0.042	10
spring	MKE	Milwaukee	BVL530, BOWA	2.498	0.763	0.218	0.050	10
summer				2.834	0.643	0.221	0.057	10
autumn				0.638	0.650	0.239	0.047	10
winter				3.586	0.689	0.244	0.061	10
spring	MSP	Minneapolis	BVL530, BOWA	2.498	0.763	0.218	0.050	10
summer				2.834	0.643	0.221	0.057	10
autumn				0.638	0.650	0.239	0.047	10
winter				3.586	0.689	0.244	0.061	10
spring	ORD	Chicago	BVL530, BOWA	2.498	0.763	0.218	0.050	10
summer				2.834	0.643	0.221	0.057	10
autumn				0.638	0.650	0.239	0.047	10
winter				3.586	0.689	0.244	0.061	10
spring	DTW	Detroit	MKG513, QAK572, (cm-BOWA)	2.498	0.699	0.235	0.047	10
summer				2.834	0.671	0.219	0.034	10
autumn				0.638	0.665	0.176	0.030	10
winter				3.586	0.629	0.251	0.043	10
spring	CLE	Cleveland	MKG513, QAK572, (cm-DOSO)	4.828	0.699	0.235	0.047	10
summer				1.643	0.671	0.219	0.034	10
autumn				2.676	0.665	0.176	0.030	10
winter				3.155	0.629	0.251	0.043	10
spring	CVG	Cincinnati	MACA, LIV573	6.787	0.680	0.241	0.050	10
summer				9.157	0.672	0.231	0.071	10
autumn				7.004	0.659	0.236	0.038	10
winter				3.233	0.666	0.302	0.048	10

spring	PAH	Paducah	CDZ571, MACA	6.787	0.677	0.260	0.046	10
summer				9.157	0.656	0.231	0.068	10
autumn				7.004	0.657	0.257	0.038	10
winter				3.233	0.641	0.313	0.040	10
spring	BNA	Nashville	CDZ571, MACA	6.787	0.677	0.260	0.046	10
summer				9.157	0.656	0.231	0.068	10
autumn				7.004	0.657	0.257	0.038	10
winter				3.233	0.641	0.313	0.040	10
spring	PIT	Pittsburg	MKG513, QAK572, (cm-DOSO)	4.828	0.699	0.235	0.047	10
summer				1.643	0.671	0.219	0.034	10
autumn				2.676	0.665	0.176	0.030	10
winter				3.155	0.629	0.251	0.043	10
spring	CMH	Columbus	MKG513, QAK572, (cm-DOSO)	4.828	0.699	0.235	0.047	10
summer				1.643	0.671	0.219	0.034	10
autumn				2.676	0.665	0.176	0.030	10
winter				3.155	0.629	0.251	0.043	10
spring	IND	Indianapolis	LIV573, BVL530, (cm-MACA & UPBU)	7.158	0.825	0.168	0.033	10
summer				12.448	0.698	0.196	0.045	10
autumn				7.480	0.690	0.200	0.039	10
winter				4.057	0.720	0.270	0.060	10
spring	STL	St. Louis	BVL530, CDZ571, (cm-MACA & UPBU)	7.158	0.835	0.180	0.027	10
summer				12.448	0.680	0.195	0.041	10
autumn				7.480	0.689	0.216	0.039	10
winter				4.057	0.689	0.284	0.050	10
spring	ALO	Waterloo	BVL530, BOWA	2.498	0.763	0.218	0.050	10
summer				2.834	0.643	0.221	0.057	10
autumn				0.638	0.650	0.239	0.047	10
winter				3.586	0.689	0.244	0.061	10
spring	SLC	Salt Lake City	BRID, JARB	4.050	0.347	0.344	0.264	10
summer				5.502	0.261	0.390	0.302	10
autumn				5.236	0.215	0.312	0.434	10
winter				0.425	0.400	0.373	0.158	10
spring	BOI	Boise	JARB	3.488	0.388	0.278	0.282	10
summer				7.951	0.195	0.363	0.410	10
autumn				7.334	0.189	0.230	0.556	10
winter				0.658	0.327	0.300	0.298	10
spring	BIS	Bismark	BADL, BOWA	3.714	0.464	0.353	0.143	10
summer				8.945	0.464	0.383	0.111	10
autumn				3.136	0.316	0.478	0.146	10

winter				2.935	0.589	0.291	0.076	10
spring	OMA	Omaha	BADL, BOWA	3.714	0.464	0.353	0.143	10
summer				8.945	0.464	0.383	0.111	10
autumn				3.136	0.316	0.478	0.146	10
winter				2.935	0.589	0.291	0.076	10
spring	CRW	Charleston	DOSO, GRSM, SHEN, WASH	5.241	0.509	0.349	0.065	10
summer				5.543	0.680	0.230	0.051	10
autumn				5.619	0.604	0.287	0.049	10
winter				3.828	0.593	0.297	0.042	10
spring	CON	Concord	ACAD	5.227	0.511	0.335	0.081	10
summer				3.968	0.566	0.348	0.044	10
autumn				3.332	0.554	0.321	0.063	10
winter				4.011	0.580	0.305	0.060	10